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May 1979

Research and Development

Data Analysis of Drinking Water Asbestos Fiber Size

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EPA-600/1-79-020
May 1979

DATA ANALYSIS OF DRINKING WATER ASBESTOS FIBER SIZE

by

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Order No. CA-7-3036-J-I

Project Officer

James R. Millette
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HEALTH EFFECTS RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
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FOREWORD

The U.S. Environmental Protection Agency was created in response to increasing public concern about the dangers of pollution to the health and welfare of the American people and their environment. The complexities of environmental problems originate in the deep interdependent relationships between the various physical and biological segments of man's natural and social world. Solutions to these environmental problems require an integrated program of research and development using input from a number of disciplines.

The Health Effects Research Laboratory was established to provide sound health effects data in support of the regulatory activities of the EPA. Evaluating man's exposure to environmental health hazards is a key segment in developing such a data bank. Studies of exposure require identification, characterization, and quantification of physical, chemical, and biological agents found in the environment. In addition, exposure assessment involves the determination of conditions that cause agents to be released into the environment, the study of the routes and pathways to man, and research into the body's ability to prevent the entrance of environmental hazards.

This report presents the results of statistical comparisons of the sizes of asbestos fibers found in various types of drinking water supplies. Because the body may handle asbestos fibers of various sizes in different ways, it is important to study the sizes of fibers to which man is exposed from drinking water.

R. J. Garner
Director
Health Effects Research Laboratory

ABSTRACT

A statistical study of asbestos fiber size characteristics was conducted using data obtained from a variety of San Francisco Bay Area water systems. Particular emphasis was placed on comparison of fiber length distributions for samples collected from pre and post asbestos cement (AC) pipe systems. Significant differences were detected between the fiber size distributions in samples of raw water and water collected after a length of AC pipe. Little difference was detected between the fiber size distributions of a raw water sample and a treated water sample. It was also shown that before and after AC pipe, fibers in the water differed most significantly in the length distributions of narrow fibers.

This report was submitted in fulfillment of order CA-7-3036-J-I by Michael E. Tarter of the University of California, Berkeley. This report covers a period from August 16, 1977, to June 30, 1978.

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ACKNOWLEDGMENTS

The cooperation of Jack C. Murchio and Lorene A. Jackson, who provided considerable insight into the asbestos problem, is gratefully acknowledged. GRAFSTAT program options were implemented by Jansin T. Wong-Lee. Technical assistance was provided by Susan B. Lum.

SECTION 1

INTRODUCTION

In this paper, with very few exceptions, information is presented in one of the following three forms: 1) histograms, where estimated probability of occurrence, i.e., the estimated distribution density of the variable under consideration, is presented on the y-axis and plotted against the value of the variable (See [2] Section 2), 2) nonparametric density estimates which are similar to histograms but tend to be both smoother and more data-efficient (See [2] Sections 3 through 5), and 3) cumulative distribution estimates which are essentially indefinite integrals of the nonparametric density estimates. Specifically, both the histogram and the nonparametric density estimate associate the relative odds or chance $y=\hat{f}(x)$ on the y-axis, to the observed length x of the fiber on the x-axis. The cumulative distribution estimator associates the chance $y=\hat{F}(x)$ of observing an asbestos fiber of a given length x, <u>or a smaller length</u>, to x.

For each set of comparisons the above three estimates will be presented in reverse order with $\hat{F}(x)$ shown first, optimized nonparametric $\hat{f}(x)$ second and histogram $\hat{f}(x)$ last. This choice of presentation was motivated by the fact that significant differences between cumulatives $\hat{F}(x)$ are easier to confirm than differences between optimized nonparametric $\hat{f}(x)$. On the other hand, once the difference between two $\hat{F}(x)$ has been confirmed, optimized nonparametric $\hat{f}(x)$ tend to show where or for what values of x, differences occur. Conventional histograms are presented last because, as described in [2] Section 2, in a more detailed analysis, one may wish to view the sample rather than to simply utilize the sample to infer properties of a population or, differences or lack of differences between populations.

Information about the various sites is presented in order of increased statistical significance or decreased p-value of estimated difference. For example, despite large sample sizes, n = 318 and n = 658, Crystal Springs raw water and San Andreas treated water samples yielded almost identically shaped estimated fiber length distributions. Roughly speaking, this suggests that the effect of treatment is constant or non-existent for all fiber lengths for these groups. In the next section this finding will be described in detail. Understandably, the more complex the combination of variables used, the more likely it is for one to be able to discern differences. Specifically, when the lengths of the narrowest and the thicker fibers are considered separately, it was found that one could more clearly visualize the difference between pre- and post- A/C pipe samples of the narrowest fibers. Examples of the above finding are presented towards the end of this paper in keeping with the low-to-high level of significance order of presentation.

It should also be noted that detailed information about the nature and location of data sources can be found in Reference 1.

SECTION 2

SAN FRANCISCO WATER DISTRICT RAW WATER AND TREATED WATER COMPARISONS

Although the graph shown in Figure 1 may appear to be a single curve, it is in actuality two estimated cumulatives of fiber length distributions. One curve is constructed using data from samples of Crystal Springs raw water and the other using samples of San Andreas treated water. The Crystal Springs water flows into the San Andreas Reservoir and then through the San Andreas treatment plant before distribution to the consumers. The Crystal Springs raw water and San Andreas treated water asbestos counts are representative of water before and after treatment. The near identity of these two estimated distributions is implied by the bottom two lines of Figure 1. The maximum difference between the two estimated cumulatives is 0.14488E-01 = 0.14488E times 10^{-1} = 0.014488. Using the conventional Kolmogorov-Smirnov two sample-two sided test (See [3] pp. 127-36) a maximum difference of .92769E-01 would be necessary to assert, with an $\alpha = .05$, that there is a difference between the two groups. Naturally, an absence of evidence of population difference does not necessarily imply that the populations are statistically identical. However, in light of the large sample sizes involved, Figure 1 strongly suggests that the San Andreas water treatment, which consists of coagulation, filtration flocculation, caustic soda, fluoridation and chlorination, is not affecting asbestos fiber length distribution.

As an exercise in interpreting Figure 1, consider a line segment drawn parallel to the x-axis which begins at the 0.5000 value midway up the y-axis, intercepts the curve $y=\hat{F}(x)$ and then changes direction and descends vertically until it intercepts the x-axis at a point close to x = 1. This value, x = 1 is identical to the estimated median of both the sample size n = 318 and n = 658 group. In general, the numbers printed below each graph provide reference points, e.g., the 50th percentile = 1, to be used for comparison purposes.

In all but one set of figures in this paper the post-treatment sample will be described in the leftmost column headed by EXCL GRP (x) and the pre-treatment samples will be described in the column headed by INCL GRP(T). Usually the sample sizes will be large for the post-treatment samples, e.g., across from the word SAMPLE, under the symbols EXCL GRP(x), N = 658 while n = 318 for the pre-treated sample.

Figure 2 corresponds to Figure 1 with the exception that the estimated population probability densities, $\hat{f}(x)$, are displayed in place of the estimated population cumulatives, $\hat{F}(x)$. The wavy shape of the estimated probability density in the tail or extreme value regions is either due to samp-

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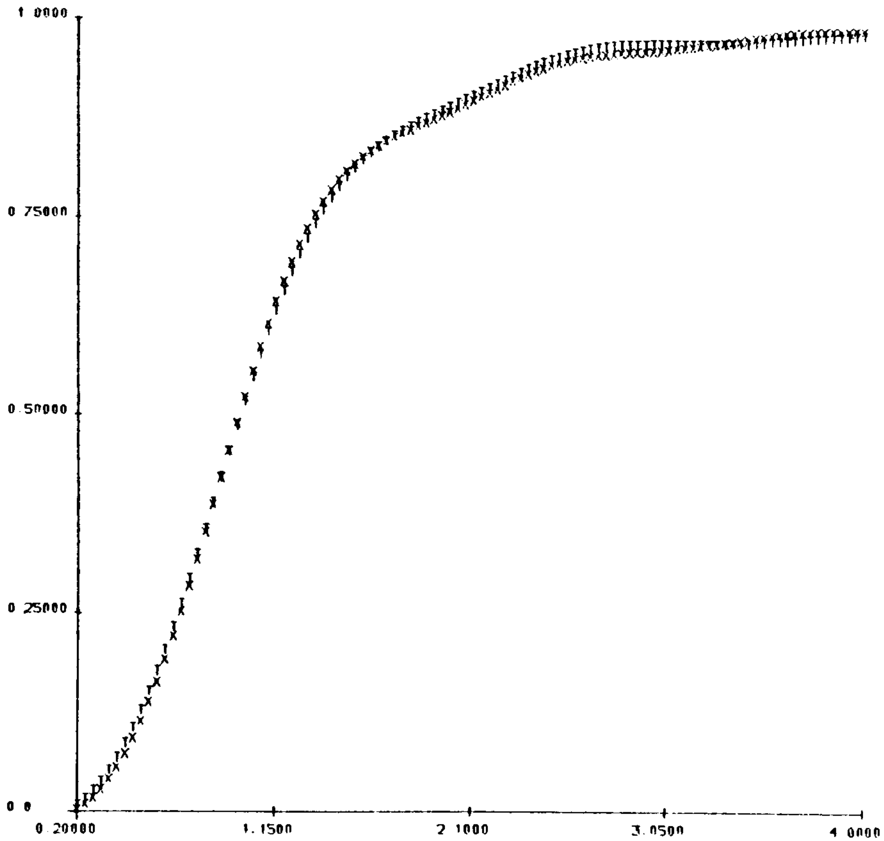

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SAMPLE	663	318
EST.MU	0.84600	0.84600
EST.SGMA	0.42025	0.44943
EST.MAX	0.91251	0.85515
MEDIAN	1.0000	1.0000

MAX DIF = 0.14488E-01
SIG. PT (0.05) = .92769E-01

Figure 1. Comparison of cumulative estimated fiber length data for raw and treated water (X axis scaled in microns).

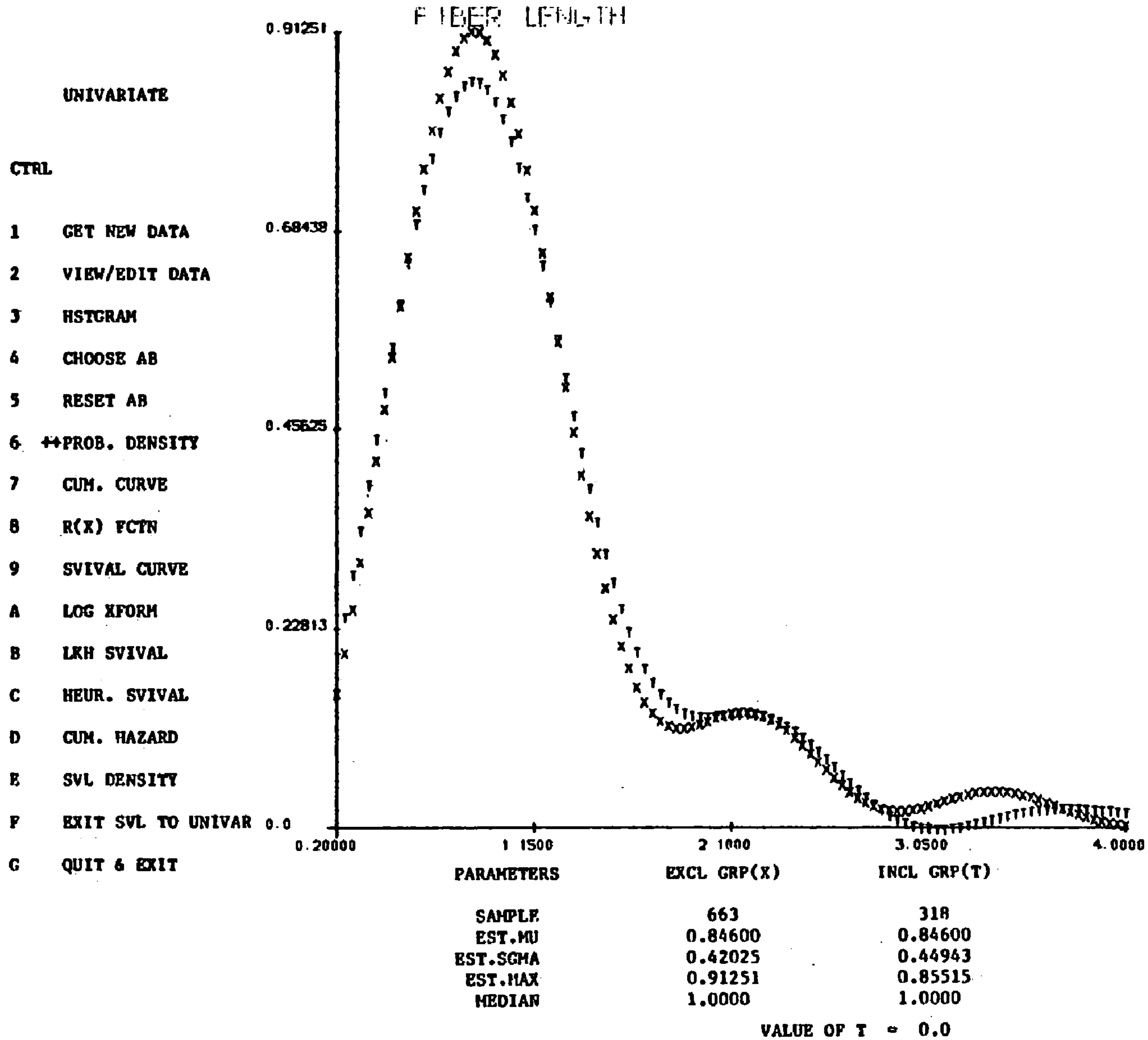

Figure 2. Comparison of estimated length density function data for raw and treated water (X axis scaled in microns).

ling variation or the discrete nature of the asbestos fiber length measurement process.

Unlike the estimated probability densities shown in Figure 2, the histograms of San Andreas and Crystal Springs fiber length distributions are uncorrected for sampling variation. However, due to the large sample sizes available the two histograms are remarkably similar and lend a great deal of support to the assertion that the fiber length populations under consideration are statistically identical.

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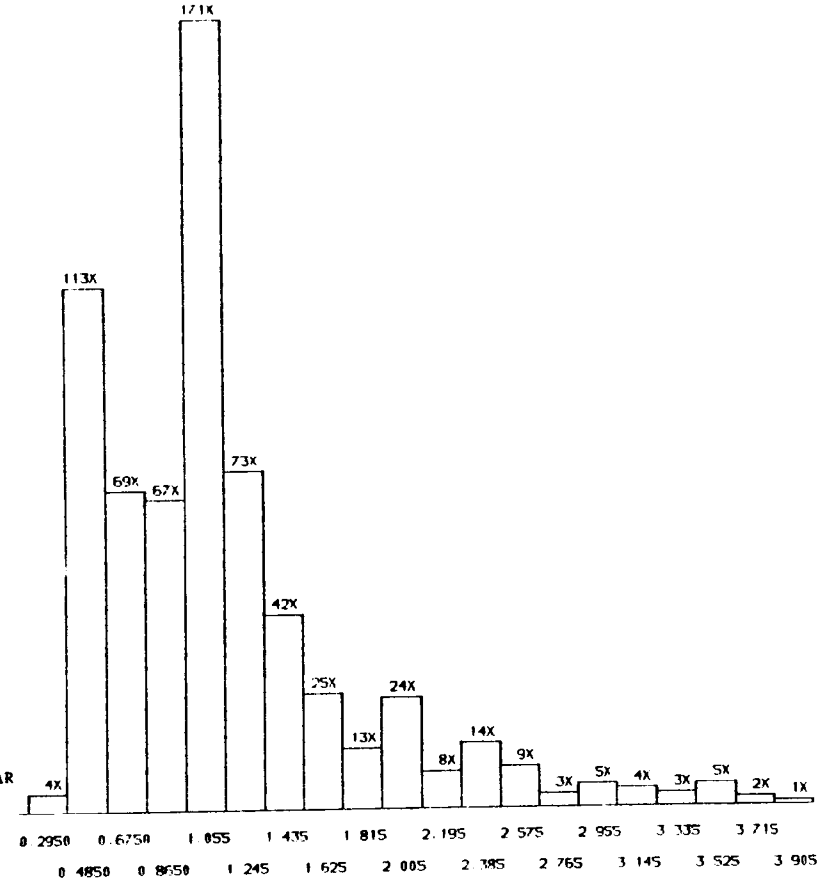

PARAMETERS	EXCL GRP(X)	INCL GRP(T)
SAMPLE	663	318
EST.MU	0.84600	0.84600
EST.SGMA	0.42025	0.44943
EST.MAX	0.91251	0.85515
MEDIAN	1.0000	1.0000

Figure 3. Histogram of San Andreas treated water fiber length data (micron X axis scale).

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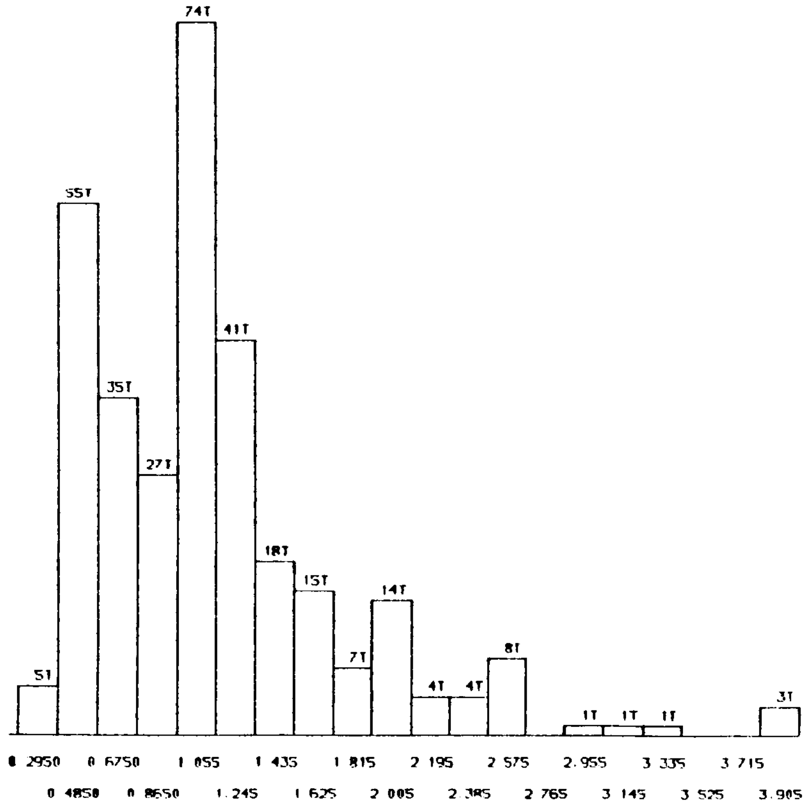


PARAMETERS	EXCL GRP(X)	INCL GRP(T)
SAMPLE	663	318
EST.MU	0.84600	0.84600
EST.SGMA	0.42025	0.44943
EST.MAX	0.91251	0.85515
MEDIAN	1.0000	1.0000

Figure 4. Histogram of Crystal Springs raw water fiber length data (micron X axis scale).

SECTION 3

EAST BAY MUNICIPAL UTILITY DISTRICT (EBMUD) COMPARISON BEFORE AND AFTER FLOW THROUGH AC PIPE

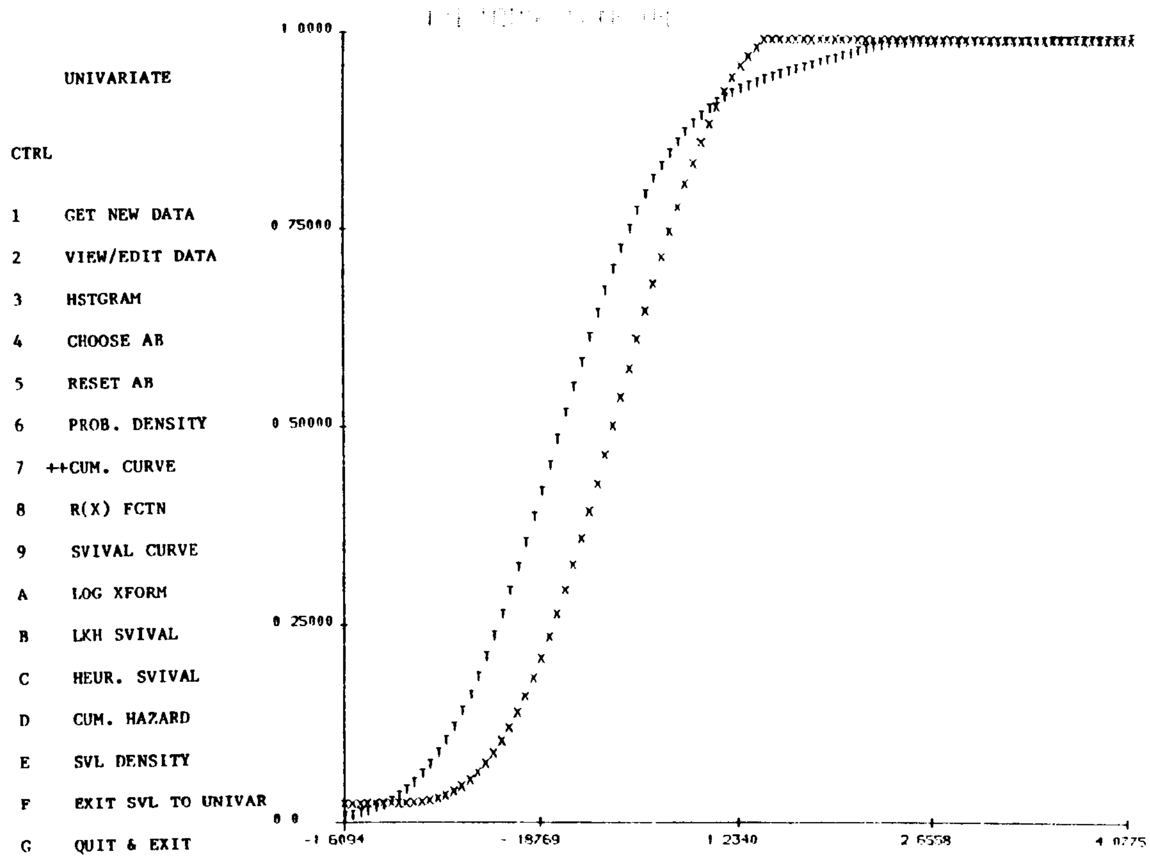
For reasons to be described later in this section, the natural logarithm of fiber length was used as the x - axis variable in Figures 5 through 8. To convert any of the numbers on the x - axis to the usual arithmetic scale one can use a table of exp(x) or, somewhat less conveniently a table of logarithms; e.g., the median for before AC pipe, 0, is equivalent to a fiber length of exp(0) = 1. In this one instance the sample size, n = 123, available for the before AC pipe group is larger than that, n = 24, for the after AC pipe group.

The after AC pipe distribution appears to be shifted to the right relative to the before AC pipe distribution. However, since the observed maximum difference equals 0.22444, which is smaller than the Kolmogorov-Smirnov critical value of 0.30369, the difference between the populations cannot be said to be significant for the sample sizes available.

One advantage of using a logarithmic transformation of fiber length data is illustrated by the population density estimates shown in Figure 6. The symmetry, homoscedasticity and bell-shape of these curves suggests that a distribution-dependent-test for group difference might be preferable to the Kolmogorov-Smirnov test which, although asymptotically distribution-free, tends to have lower power than the latter test. However, in light of more clear-cut results to be described in later sections of this paper, further statistical elaboration for EBMUD data was not considered.

The two histograms shown in Figures 7 and 8 again tend to illustrate the tendency towards discreteness or clumping of asbestos fiber length data. Also note the possible "outlier" which occurs at a considerable distance from the next largest value in Figure 8. Since this outlier was brought closer to the main body of data by the logarithmic transformation its apparent separation from the other data values would have been considerably greater in a plot constructed by using an arithmetic scale as is shown in Figure 9.

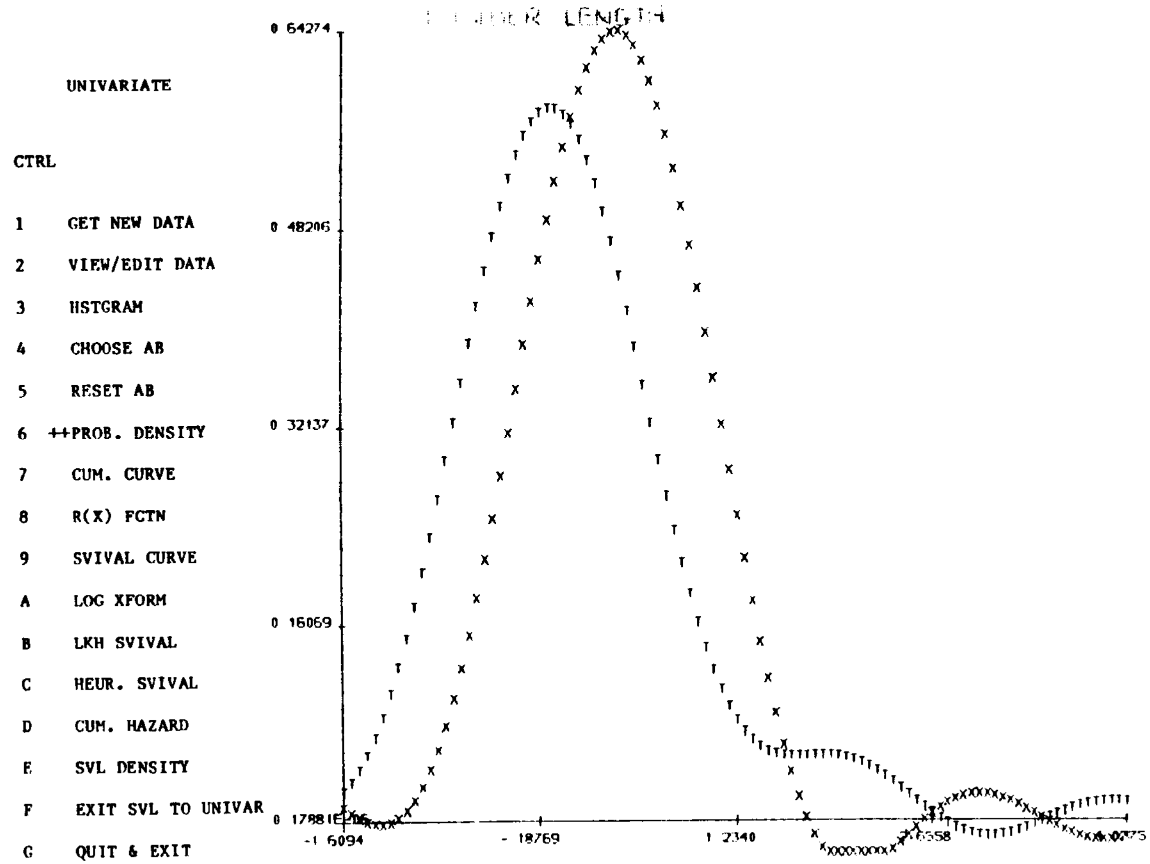
The numerical value of the possible outlier was determined by plotting the sample code number against fiber length using the GRAFSTAT light pen sensing option. (This and other GRAFSTAT data editing and identification options are described in [4] and [5]). The fiber length determined by this process was 58.721 microns as shown in Figure 9.



PARAMETERS	EXCL GRP(X)	INCL GRP(T)
SAMPLE	24	123
EST.MU	0.38100	-.13083
EST.SGMA	0.61801	0.68323
EST.MAX	0.64274	0.58000
MEDIAN	0.22234	0.0

MAX DIF = 0.22444
SIG. PT (0.05) = .30349

Figure 5. Estimated cumulative plot of EBMUD fiber length data (X axis scaled in log micron units).



PARAMETERS	EXCL GRP(X)	INCL GRP(T)
SAMPLE	24	123
EST.MU	0.38100	-.13083
EST.SGMA	0.61801	0.68323
EST.MAX	0.64274	0.58000
MEDIAN	0.22234	0.0

VALUE OF T = 3.4065

Figure 6. Estimated population density plots of EBMUD fiber length data (X axis scaled in log micron units).

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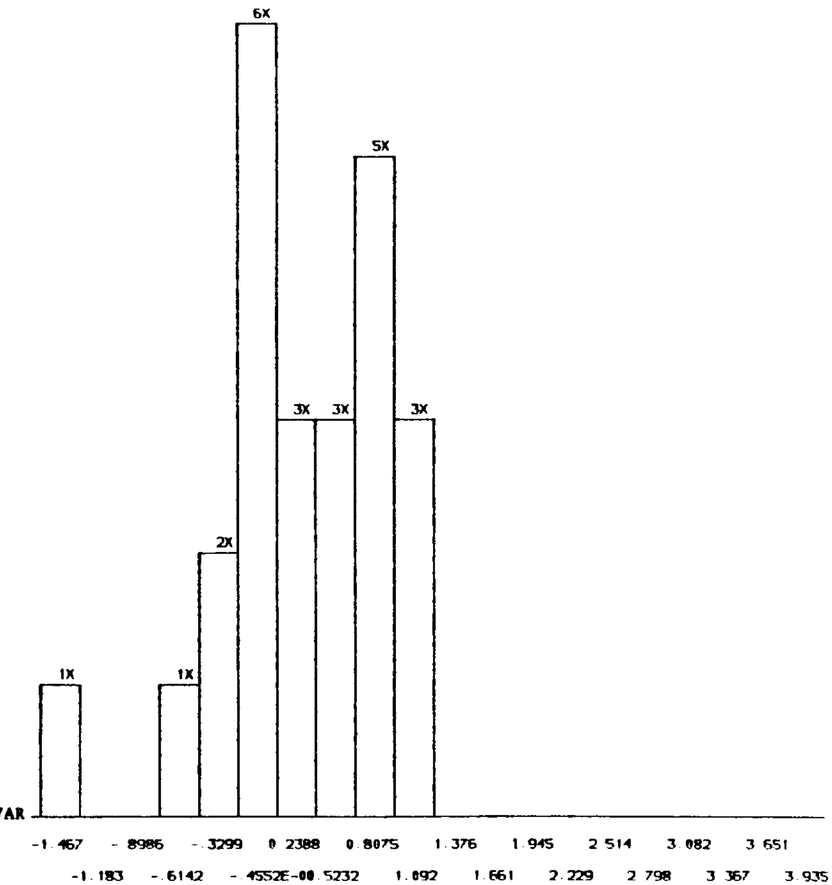

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EST.MU	0.38100	-.13083
EST.SGMA	0.61801	0.68323
EST.MAX	0.64274	0.58000
MEDIAN	0.22234	0.0

Figure 7. Histogram of fiber length data after A/C pipe (X axis log micron scale).

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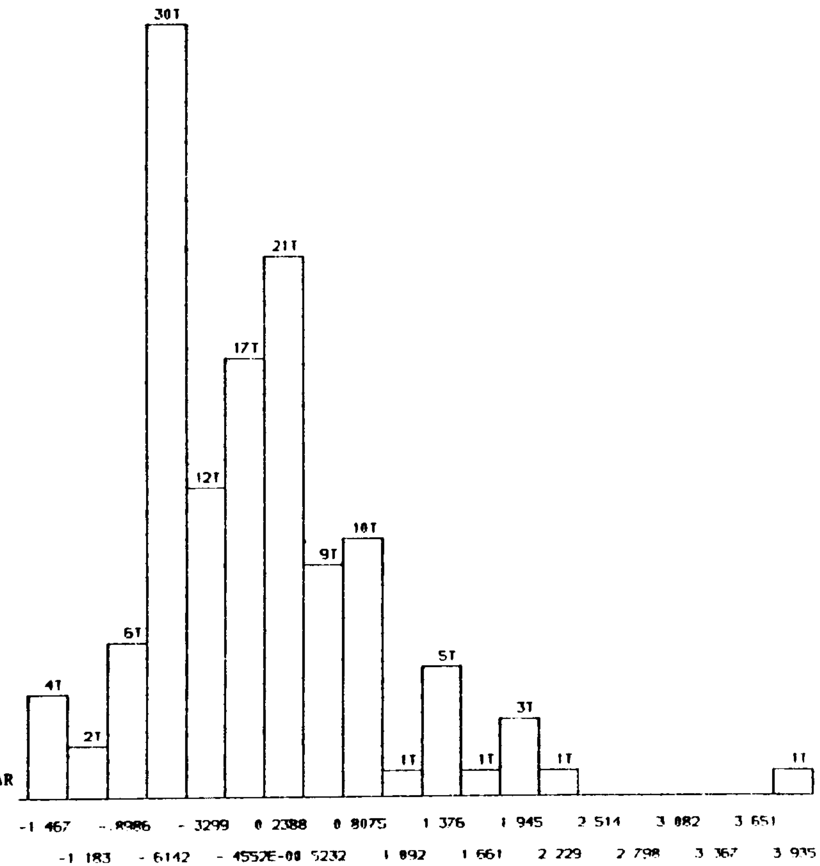

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PARAMETERS	EXCL GRP(X)	INCL GRP(T)
SAMPLE	24	123
EST.MU	0.38100	-.13083
EST.SGMA	0.61801	0.68323
EST.MAX	0.64274	0.58000
MEDIAN	0.22234	0.0

Figure 8. Histogram of fiber length data before A/C pipe (X axis log micron scale).

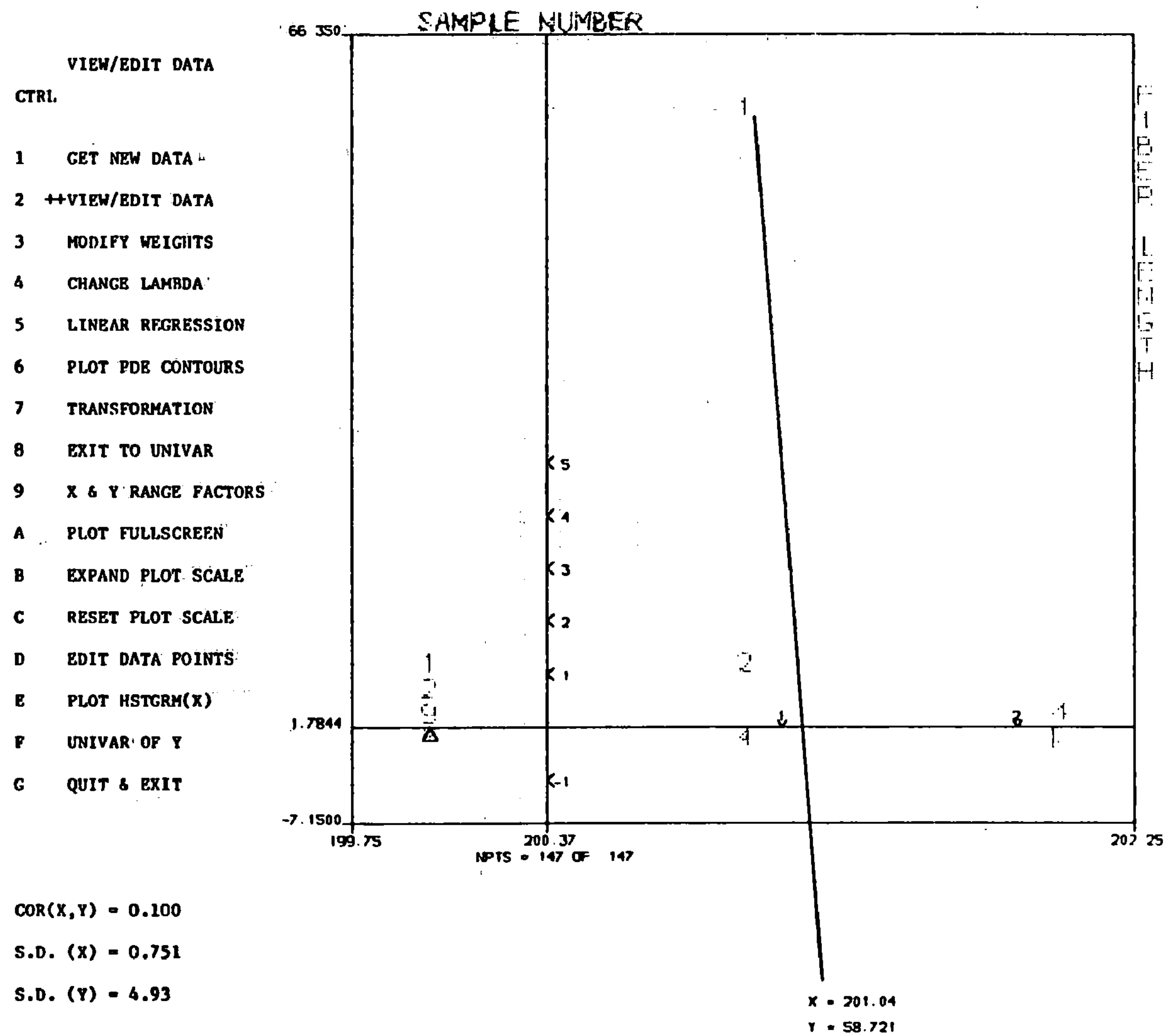

Figure 9. Frequency diagram for sample number plotted against fiber length (Y axis micron scale).

Each number or letter of Figure 10 indicates the number of data points at a specific sample index-number, length in microns, coordinate. For example the letter C, at the mean fiber length y coordinate 1.3925 of leftmost group 200 indicates, since C is the third letter of the alphabet, that 9 + 3 = 12 (the number of non-zero digits + the position of C in the alphabet) points takes on the value 1.3925 within the group indexed by the number 200 (which corresponds to the before treatment subgroup).

Note that after the grouping option has been executed, there are 123-1 = 122 points in the second group (as indicated on the third line from the bottom) due to the removal of the possible outlier.

With the exception of the one possible outlier, whose removal was previously described, Figure 11 is the arithmetic scale equivalent of Figure 6. Note that the median of 0.0 appearing in the second column of Figure 4 corresponds to the value exp(0) = 1 of Figure 11.

The slight, but not necessarily statistically significant, shift to larger fiber lengths after flow through A/C pipe is illustrated in Figures 11, 12 and 13.

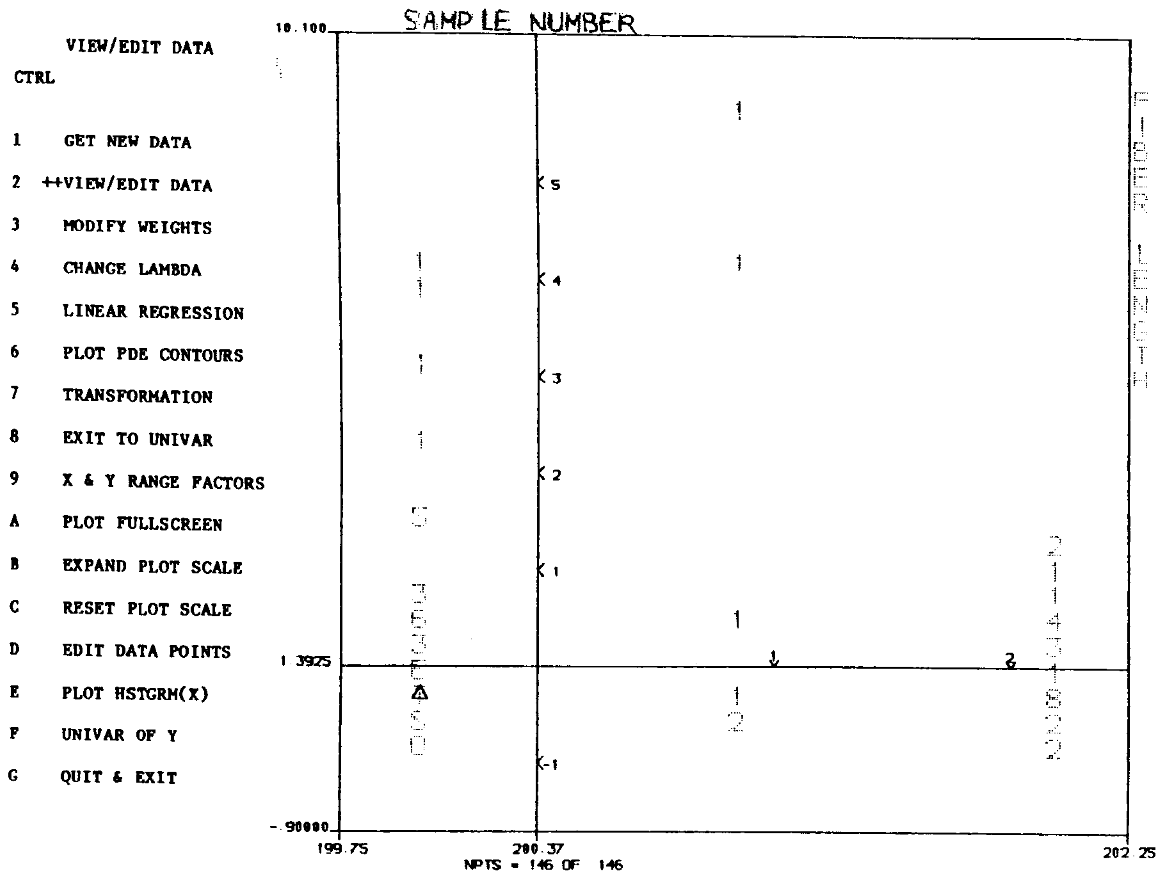

Figure 10. Frequency diagram after elimination of possible outlier (Y axis micron scale).

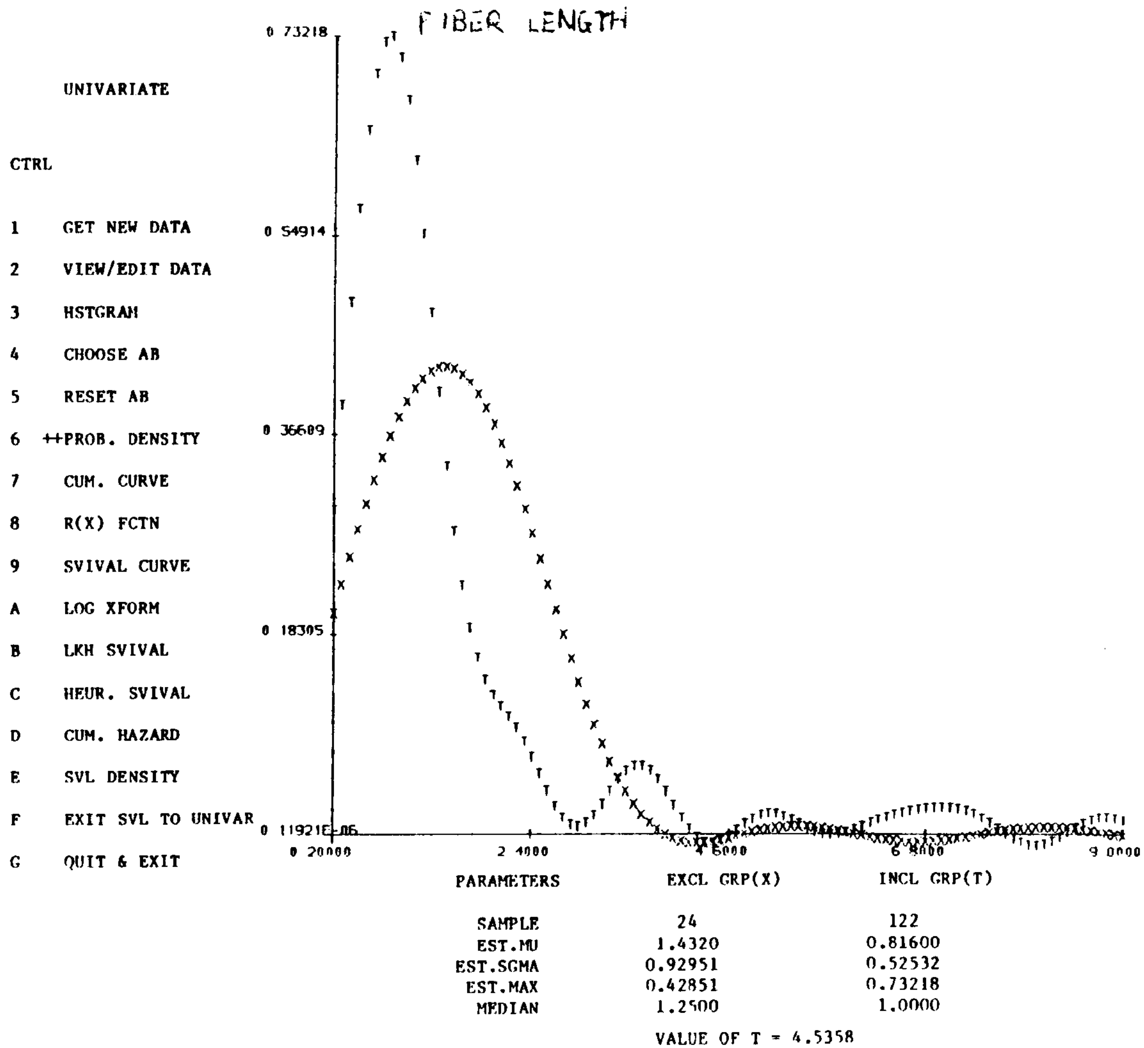

Figure 11. Estimated population density plots of EBMUD fiber length data (X axis in micron scale).

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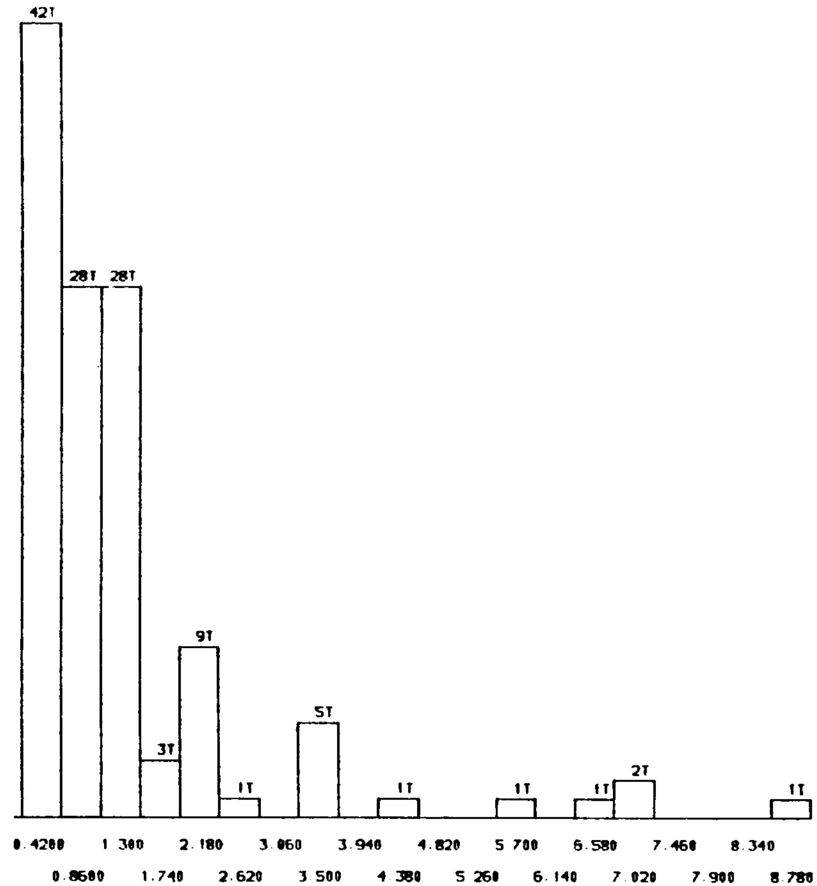

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PARAMETERS	EXCL GRP(X)	INCL GRP(T)
SAMPLE	24	122
EST.MU	1.4320	0.81600
EST.SGMA	0.92951	0.52532
EST.MAX	0.42851	0.73218
MEDIAN	1.2500	1.0000

Figure 12. Histogram of EBMUD fiber length data after A/C pipe (X axis micron scale).

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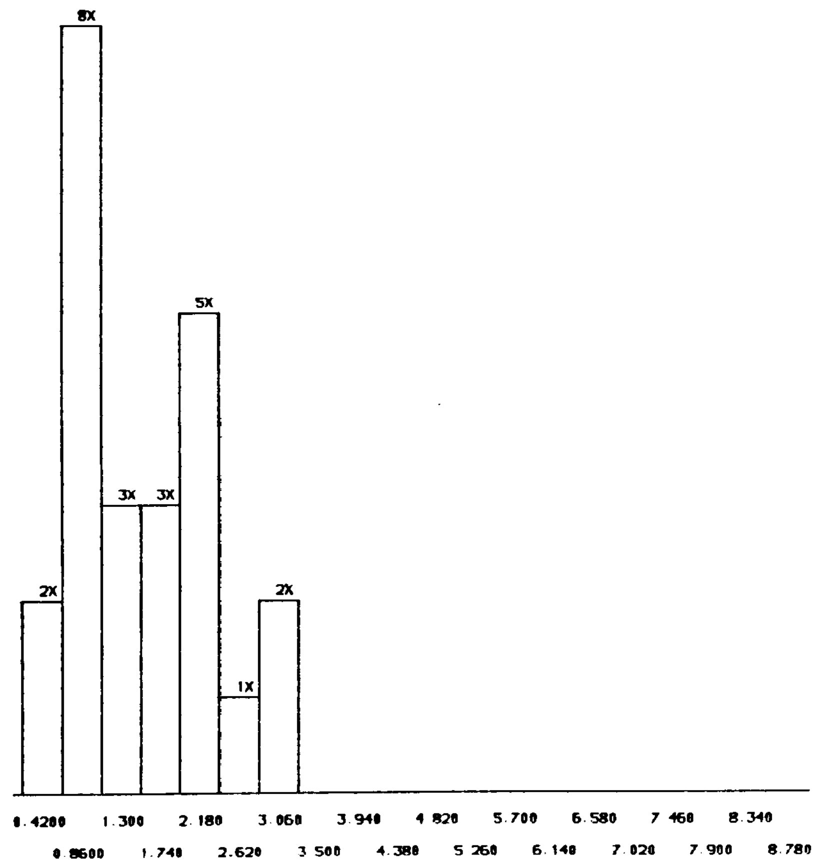

NO. OF INTERVAL = 20

PARAMETERS	EXCL GRP(X)	INCL GRP(T)
SAMPLE	24	122
EST.MU	1.4320	0.81600
EST.SGMA	0.92951	0.52532
EST.MAX	0.42851	0.73218
MEDIAN	1.2500	1.0000

Figure 13. Histogram of EBMUD fiber length data before A/C pipe (X axis micron scale).

SECTION 4

SAN FRANCISCO WATER DEPARTMENT HETCH-HETCHY (HH) BEFORE AND AFTER FLOW THROUGH ASBESTOS CEMENT PIPE

Before proceeding to data analyses which produced positive findings, it seems appropriate to present an analysis which, possibly due to sample size considerations, seems to contradict the trends suggested in the previous section. In this instance, unlike the previous data, a larger sample was available for after than for before AC piped water.

The cumulatives shown in Figure 14 differ substantially from their Figure 5 counterparts. Unlike those of Figure 5, Figure 14 cumulatives cross each other. This finding would not be affected by use of a logarithmic or any other conventional data transformation.

Two features which differentiate HH and EBMUD fiber length distributions are indicated by Figure 15. Despite the small sample size of n = 15, one can probably infer that the before AC pipe fiber lengths are associated with a two component distribution. It is also apparent that at least before logarithmic transformation, both before and after AC pipe data is highly clumped.

The skewed shape of the after AC pipe and the possibly two component structure of the before AC pipe fiber length distributions is discernible from the two histograms shown in Figures 16 and 17.

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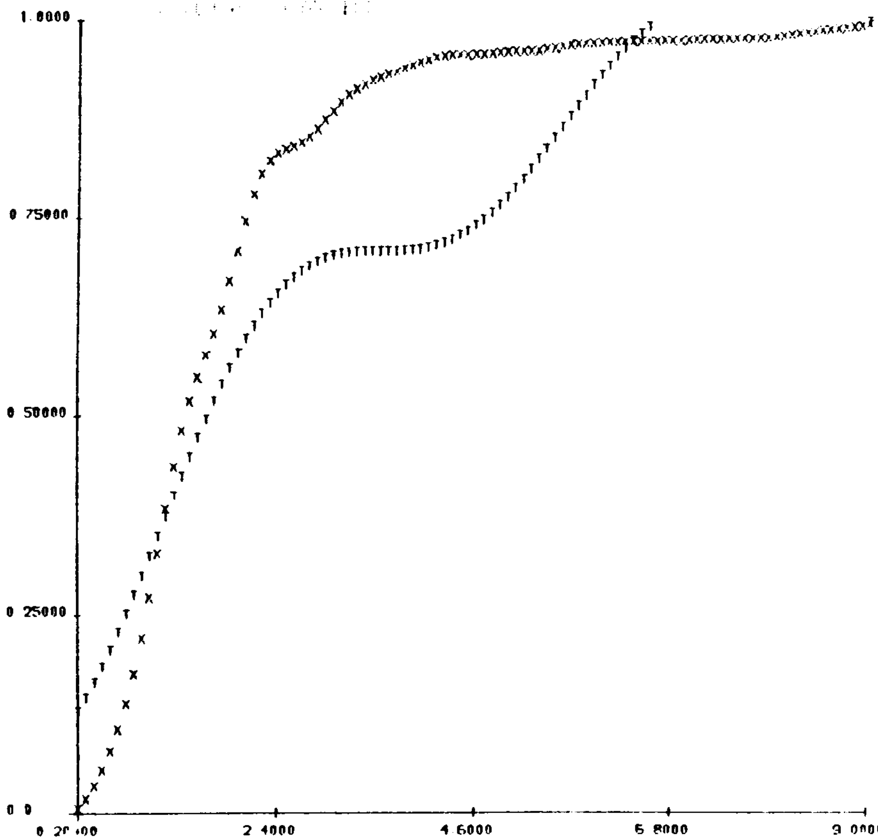
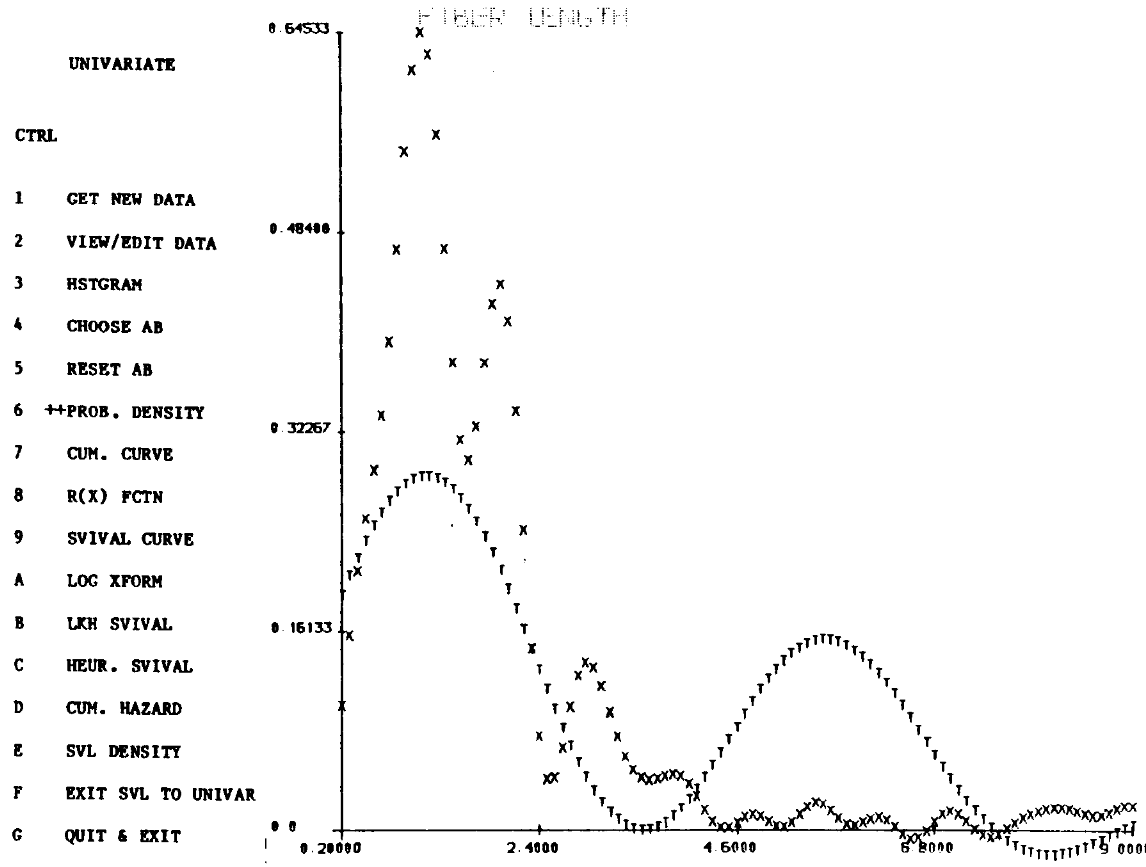


PARAMETERS	EXCL GRP(X)	INCL GRP(T)
SAMPLE	263	15
EST.MU	1.0800	1.1680
EST.SGMA	0.56163	1.3217
EST.MAX	0.64533	0.28742
MEDIAN	1.4000	1.2000

MAX DIF = 0.23763

SIG.PT(0.05) = .36103

Figure 14. Estimated cumulative plots of fiber length data from the Hetch-Hetchy System (X axis micron scale).



PARAMETERS	EXCL GRP(X)	INCL GRP(T)
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EST.SGMA	0.56163	1.3217
EST.MAX	0.64533	0.28742
MEDIAN	1.4000	1.2000

VALUE OF T = -.53217

Figure 15. Estimated population density plots of fiber length data from the Hetch-Hetchy System (X axis micron scale).

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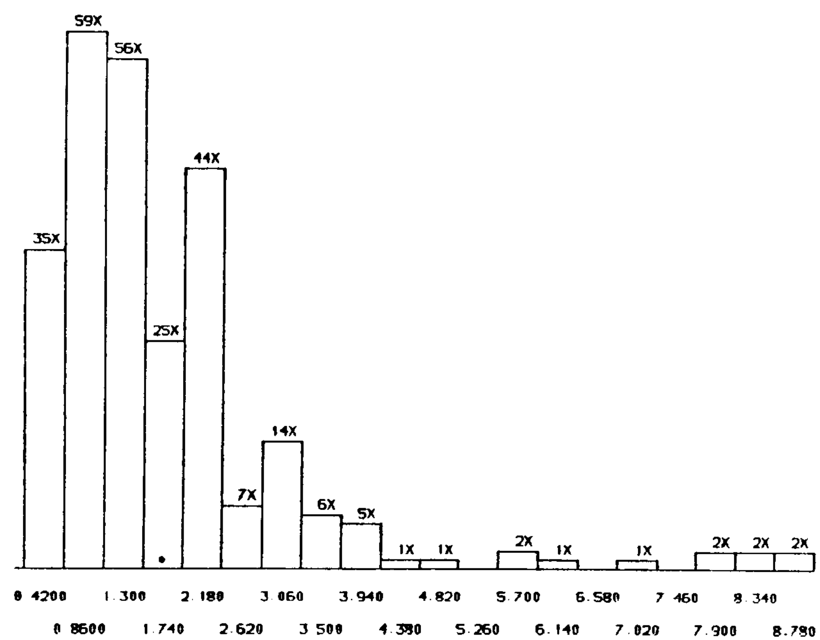

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PARAMETERS	EXCL GRP(X)	INCL GRP(T)
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EST.MU	1.0800	1.1680
EST.SGMA	0.56163	1.3217
EST.MAX	0.64533	0.28742
MEDIAN	1.4000	1.2000

Figure 16. HIstogram of fiber length data after A/C pipe from Hetch-Hetchy System (X axis in micron scale).

UNIVARIATE

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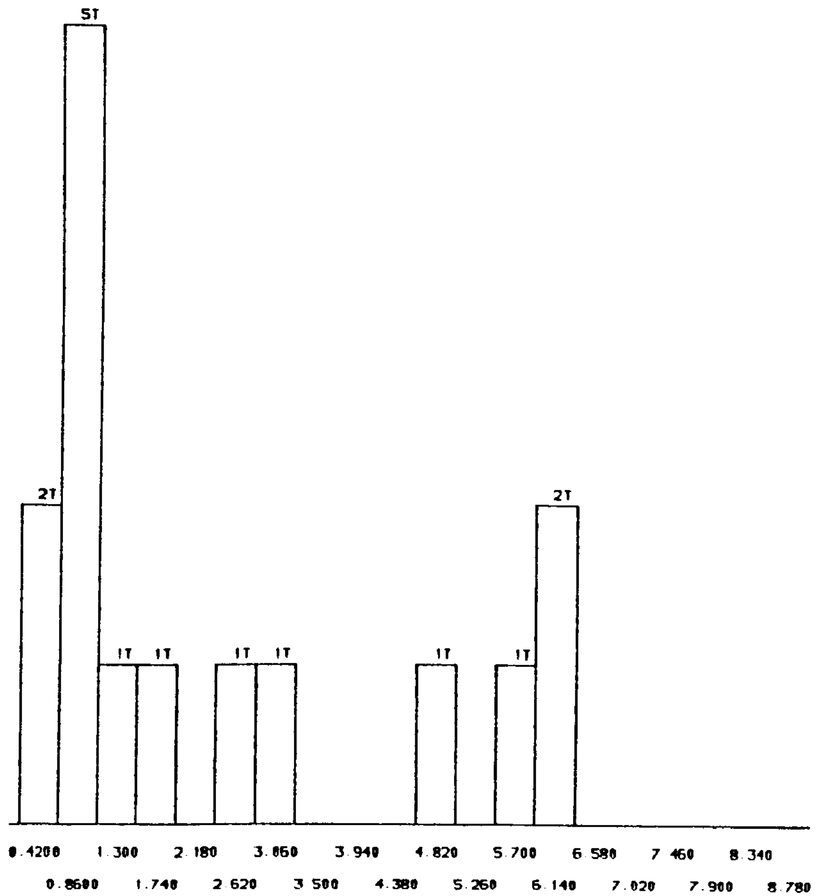


NO. OF INTERVAL = 20

PARAMETERS	EXCL GRP(X)	INCL GRP(T)
SAMPLE	263	15
EST.MU	1.0800	1.1680
EST.SGMA	0.56163	1.3217
EST.MAX	0.64533	0.28742
MEDIAN	1.4000	1.2000

Figure 17. Histogram of fiber length data before A/C pipe from Hetch-Hetchy System (X axis in micron scale).

SECTION 5

COMBINED BEFORE AND AFTER AC PIPE SAMPLES

The complex distributional forms illustrated in the previous two sections suggested that larger sized samples were required to produce definitive statistical conclusions. In this section, EBMUD and HH data were pooled in order to provide the sample size needed for detailed analysis.

After pooling EBMUD and HH data, the estimated cumulatives of Figure 18 were obtained which are almost identical in shape to those shown in Figure 5. Again the smaller fibers are more common for samples before AC pipe than after AC pipe. Unlike the statistical analysis described in Section 3, however, here the maximum cumulative difference substantially exceeds the critical point and hence the difference is significant.

Figure 19 indicated a need for still more elaborate analysis of this data as do the histograms shown in Figures 20 and 21.

In order to check on the previous finding and assess its statistical significance the Crystal Springs raw water sample was substituted for the before AC pipe pooled sample and a comparable analysis performed. Figure 22 is similar in form to Figure 18 and the difference of cumulatives is again highly significant.

This comparison would indicate that there is a significant difference between the fiber lengths of natural fibers and those found after AC pipe. The fibers found after AC pipe have a significantly larger portion of long fibers than the raw water fibers.

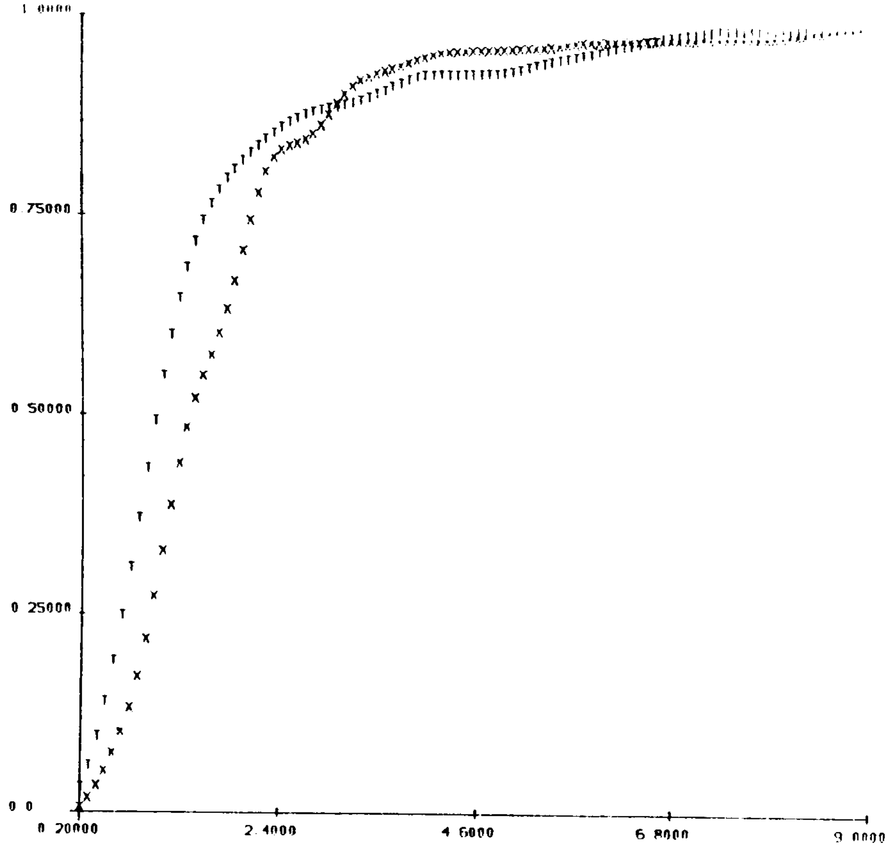
Because of the high slope of the cumulative, no density estimates were associated with the cumulatives of Figure 22. It should also be noted that the scale change needed to compare pooled after AC pipe data to Crystal Springs raw water data caused the difference between the histograms of Figure 23 and 20.

From the study reported in this section, it would appear that Crystal Springs raw water and before AC piped HH and EBMUD water distributions show similar differences with post AC piped HH and EBMUD water.

UNIVARIATE

CTRL

1 GET NEW DATA
2 VIEW/EDIT DATA
3 HSTGRAM
4 CHOOSE AB
5 RESET AB
6 PROB. DENSITY
7 ++CUM. CURVE
8 R(X) FCTN
9 SVIVAL CURVE
A LOG XFORM
B LKH SVIVAL
C HEUR. SVIVAL
D CUM. HAZARD
E SVL DENSITY
F EXIT SVL TO UNIVAR
G QUIT & EXIT



PARAMETERS	EXCL GRP(X)	INCL GRP(T)
SAMPLE	287	137
EST.MU	1.0800	1.81600
EST.SGMA	0.54862	0.53110
EST.MAX	0.66302	0.71369
MEDIAN	1.4000	1.0000

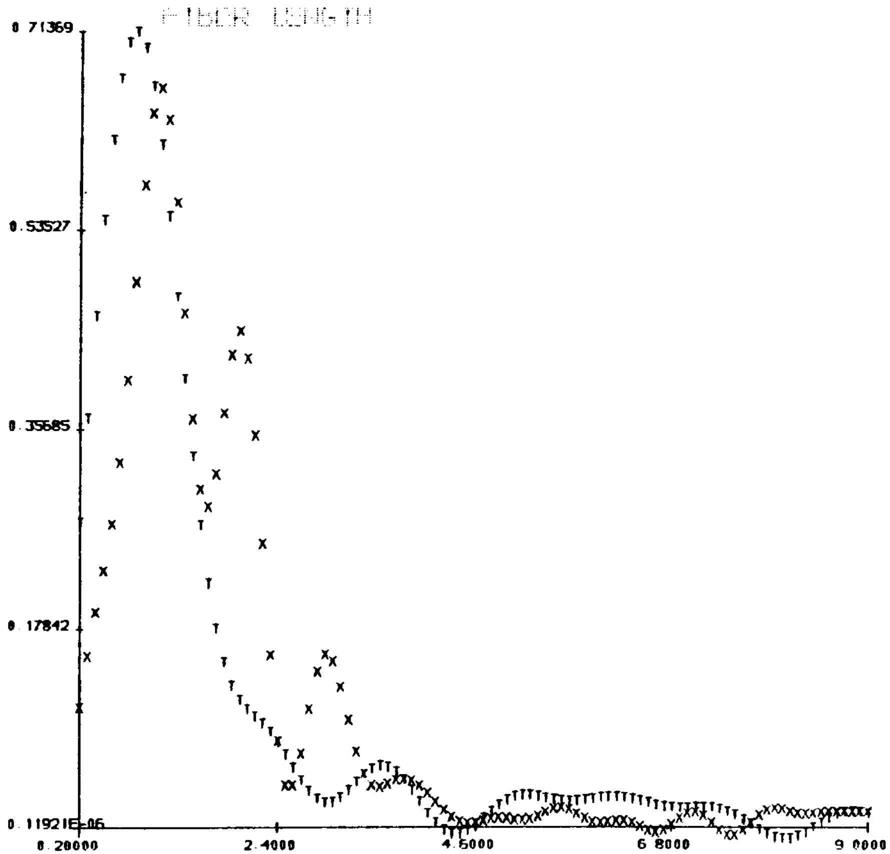
MAX DIF = 0.22170
SIG. PT(0.05) = .14123

Figure 18. Estimated cumulative plots of pooled fiber length data (X axis in micron scale, T = before, X = after).

UNIVARIATE

CTRL

1 GET NEW DATA
2 VIEW/EDIT DATA
3 HSTGRAM
4 CHOOSE AB
5 RESET AB
6 ++PROB. DENSITY
7 CUM. CURVE
8 R(X) FCTN
9 SVIVAL CURVE
A LOG XFORM
B LKH SVIVAL
C HEUR. SVIVAL
D CUM. HAZARD
E SVL DENSITY
F EXIT SVL TO UNIVAR
G QUIT & EXIT



PARAMETERS	EXCL GRP(X)	INCL GRP(T)
SAMPLE	287	137
EST.MU	1.0800	1.81600
EST.SGMA	0.54862	0.53110
EST.MAX	0.66302	0.71369
MEDIAN	1.4000	1.0000

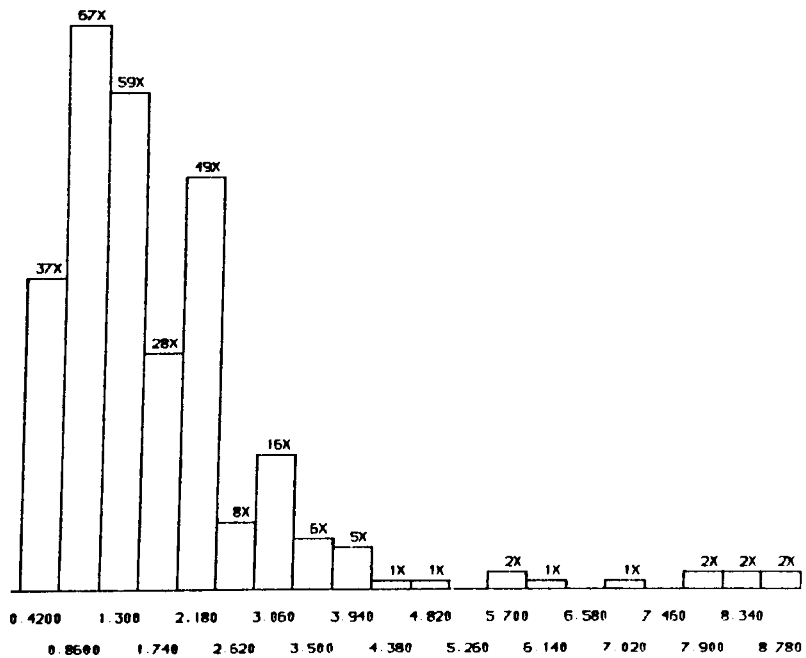
VALUE OF T = 4.6816

Figure 19. Estimated population density plots of pooled fiber length data (X axis in micron scale).

UNIVARIATE

CTRL

1 GET NEW DATA
2 VIEW/EDIT DATA
3 ++HSTGRAM
4 CHOOSE AB
5 RESET AB
6 PROB. DENSITY
7 CUM. CURVE
8 R(X) FCTN
9 SVIVAL CURVE
A LOG XFORM
B LKH SVIVAL
C HEUR. SVIVAL
D CUM. HAZARD
E SVL DENSITY
F EXIT SVL TO UNIVAR
G QUIT & EXIT



PARAMETERS	EXCL GRP(X)	INCL GRP(T)
SAMPLE	287	137
EST.MU	1.0800	1.81600
EST.SGMA	0.54862	0.53110
EST.MAX	0.66302	0.71369
MEDIAN	1.4000	1.0000

NO. OF INTERVAL = 20

Figure 20. Histogram of pooled fiber length data after A/C pipe (X axis in micron scale).

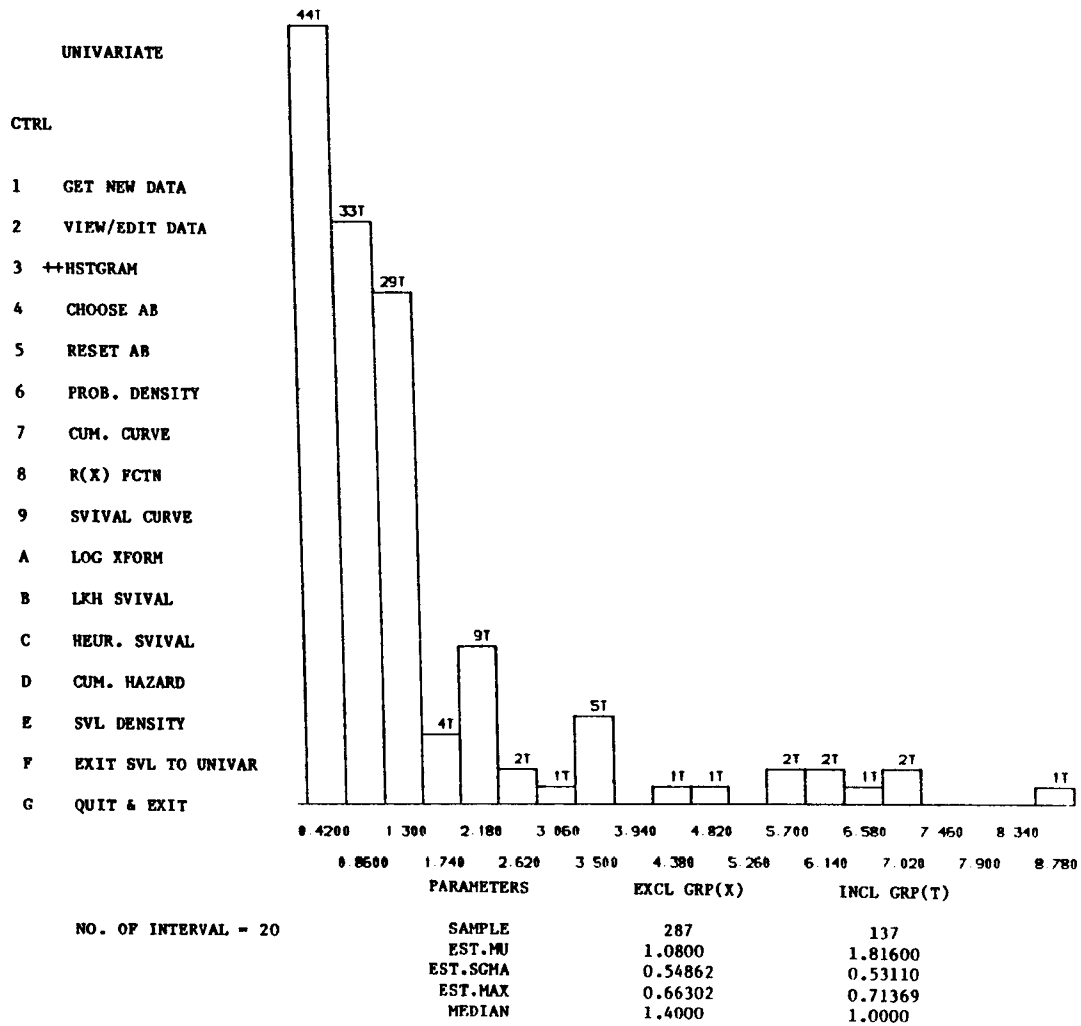
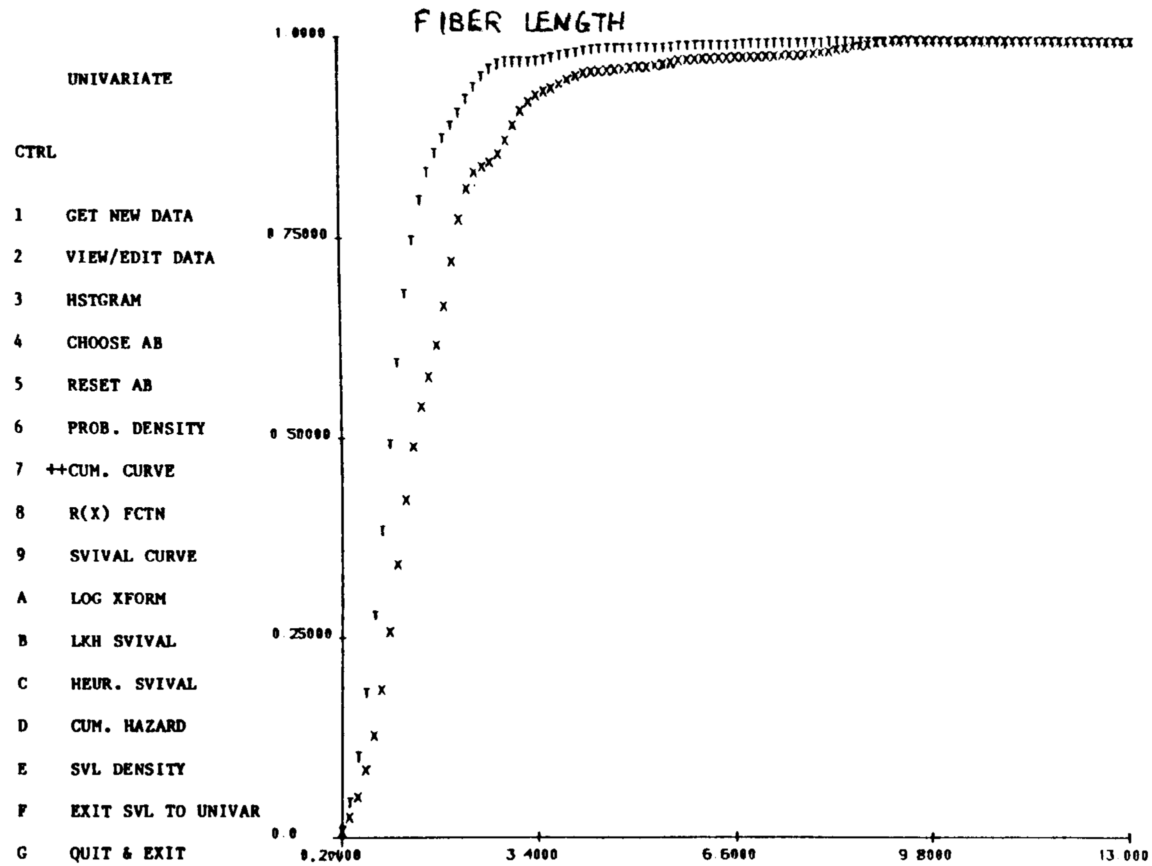


Figure 21. Histogram of pooled fiber length data before A/C pipe (X axis in micron scale).



PARAMETERS	EXCL GRP(X)	INCL GRP(T)
SAMPLE	287	318
EST.MU	1.0960	1.84000
EST.SGMA	0.55532	0.44797
EST.MAX	0.66304	0.85480
MEDIAN	1.4000	1.0000

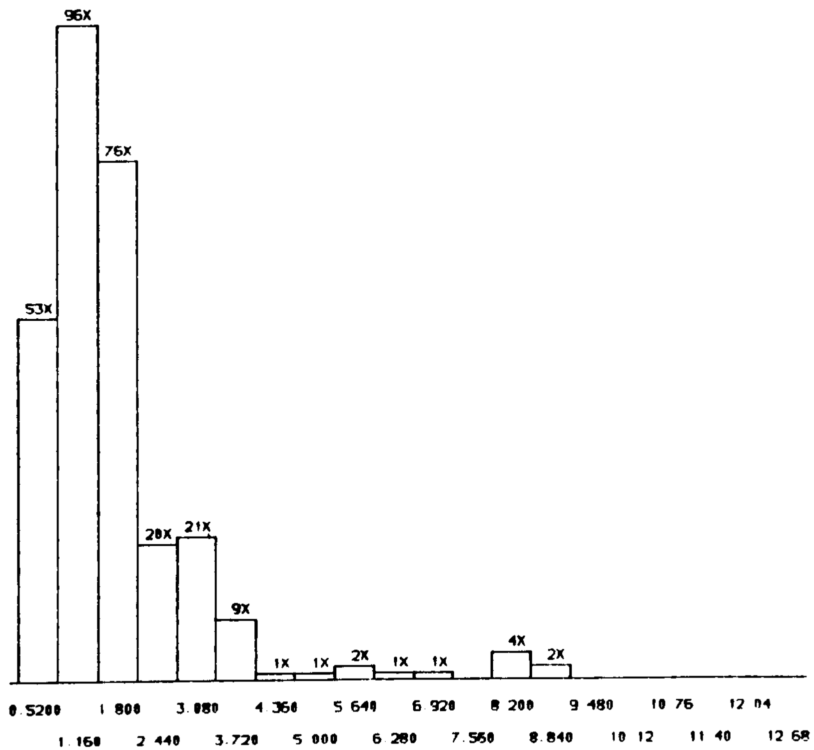
MAX DIF = 0.25901
SIG. PT (0.05) = .11073

Figure 22. Comparison of estimated cumulative plots of pooled fiber length data from raw water and after A/C pipe (X axis in micron scale, T = raw, X = after).

UNIVARIATE

CTRL

1 GET NEW DATA
2 VIEW/EDIT DATA
3 ++HSTGRAM
4 CHOOSE AB
5 RESET AB
6 PROB. DENSITY
7 CUM. CURVE
8 R(X) FCTN
9 SVIVAL CURVE
A LOG XFORM
B LKH SVIVAL
C HEUR. SVIVAL
D CUM. HAZARD
E SVL DENSITY
F EXIT SVL TO UNIVAR
G QUIT & EXIT



NO. OF INTERVAL = 20

PARAMETERS	EXCL GRP(X)	INCL GRP(T)
SAMPLE	287	318
EST.MU	1.0960	1.84000
EST.SGMA	0.55532	0.44797
EST.MAX	0.66304	0.85480
MEDIAN	1.4000	1.0000

Figure 23. Histogram of pooled fiber length data after A/C pipe (X axis in micron scale).

UNIVARIATE

CTRL

1 GET NEW DATA

2 VIEW/EDIT DATA

3 ++HSTGRAM

4 CHOOSE AB

5 RESET AB

6 PROB. DENSITY

7 CUM. CURVE

8 R(X) FCTN

9 SVIVAL CURVE

A LOG XFORM

B LKH SVIVAL

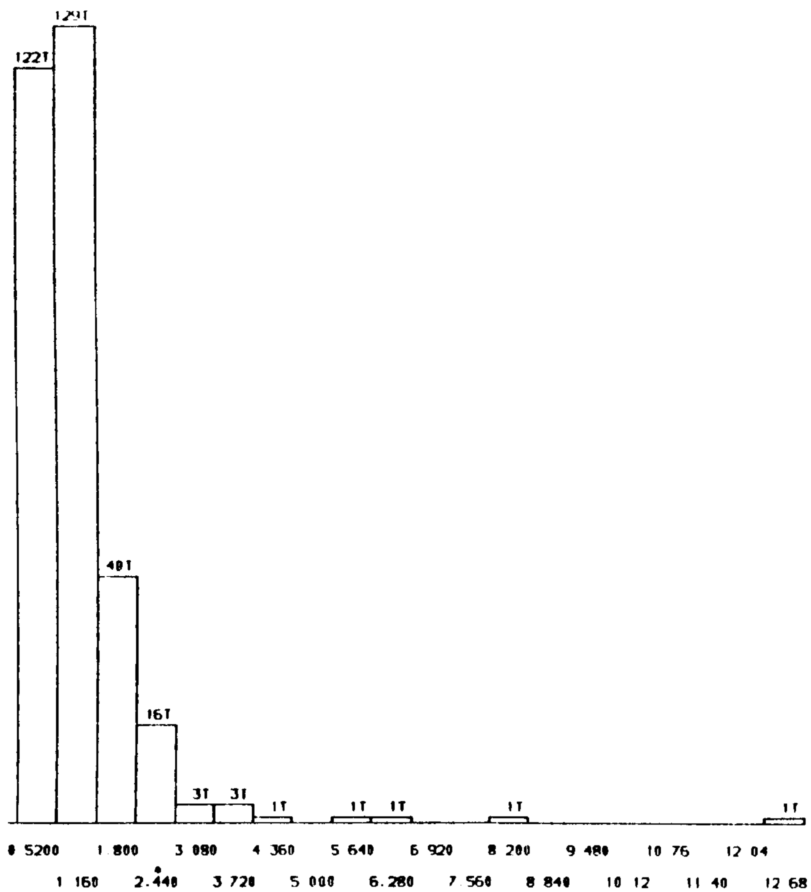
C HEUR. SVIVAL

D CUM. HAZARD

E SVL DENSITY

F EXIT SVL TO UNIVAR

G QUIT & EXIT



NO. OF INTERVAL = 20

PARAMETERS	EXCL GRP(X)	INCL GRP(T)
SAMPLE	287	318
EST.MU	1.0960	1.84000
EST.SGMA	0.55532	0.44797
EST.MAX	0.66304	0.85480
MEDIAN	1.4000	1.0000

Figure 24. Histogram of raw water fiber length data (X axis in micron scale).

SECTION 6

COMPARISON OF NARROW AND THICKER FIBERS FOR COMBINED BEFORE AND AFTER AC PIPE SAMPLES

Each number, letter or symbol within the frequency diagram of Figure 25 indicates the number of fibers (of combined before and after AC pipe samples) with a specific fiber diameter and length. Since an asterisk represents the position of thirty-five or more fibers, Figure 25 indicates that many of the narrowest fibers also seem to be fairly short. The possible existence of two distribution subgroups, (as shown in Figure 15) led to the comparison of narrow with the wide fibers with respect to their fiber length distributions. As indicated in Figure 26, the bulk of pooled before and after AC pipe data seemed to consist of narrow fibers (n = 337) 0.03 microns in width.

As shown in Figure 27, there seems to be a considerable difference between the fiber lengths of the narrowest in comparison to wider fibers. This comparison is made with the combined fiber data from before and after AC pipe. These studies, which considered the narrowest and wider fibers separately, tended to yield comparisons with high levels of statistical significance.

VIEW/EDIT DATA

CTRL

1 GET NEW DATA

2 ++VIEW/EDIT DATA

3 MODIFY WEIGHTS

4 CHANGGE LAMBDA

5 LINEAR REGRESSION

6 PLOT PDE CONTOURS

7 TRANSFORMATION

8 EXIT TO UNIVAR

9 X & Y RANGE FACTORS

A PLOT FULLSCREEN

B EXPAND PLOT SCALE

C RESET PLOT SCALE

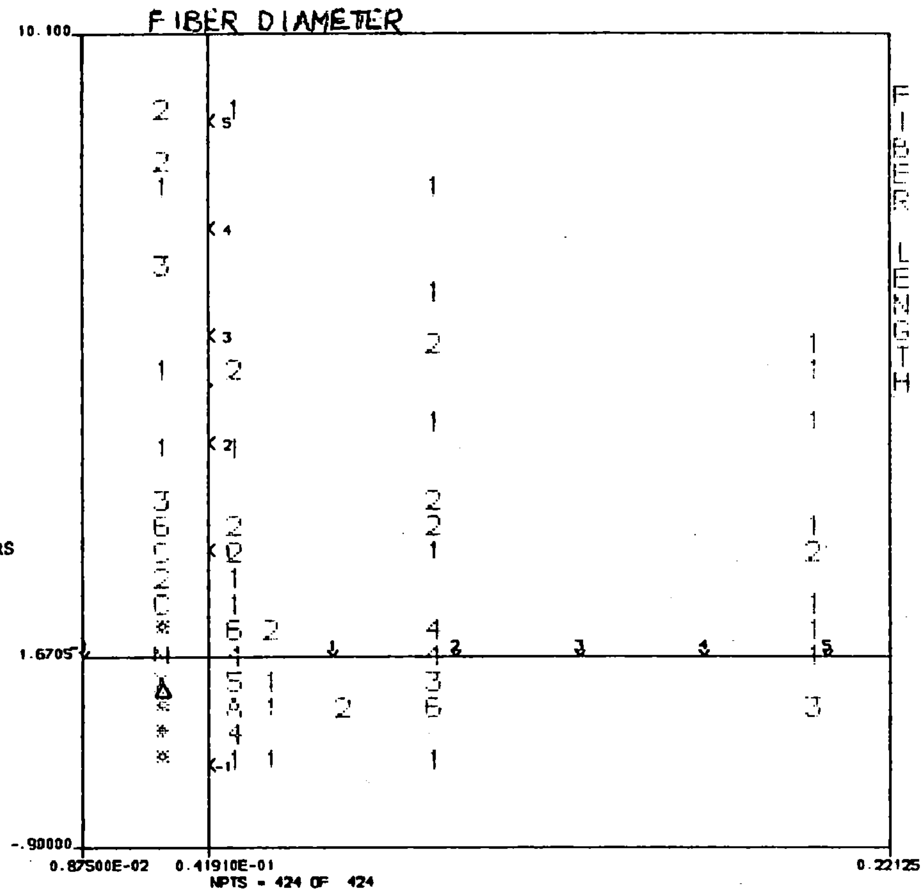
D EDIT DATA POINTS

E PLOT HSTGRM(X)

F RESTORE ORIG DATA

G UNIVAR OF Y

H QUIT & EXIT



SPECIFY UP TO 4 INTERVALS FOR DEFINING A GROUP OR FOR SPECIFICATION OF INCOMPLETE DATA.

INTERVAL	X (LEFT)	X (RIGHT)	Y (BOTH)	Y (TOP)
1	0.87500E-02	0.04000	-.90000	10.100

Figure 25. Frequency diagram showing fiber diameter against fiber length.

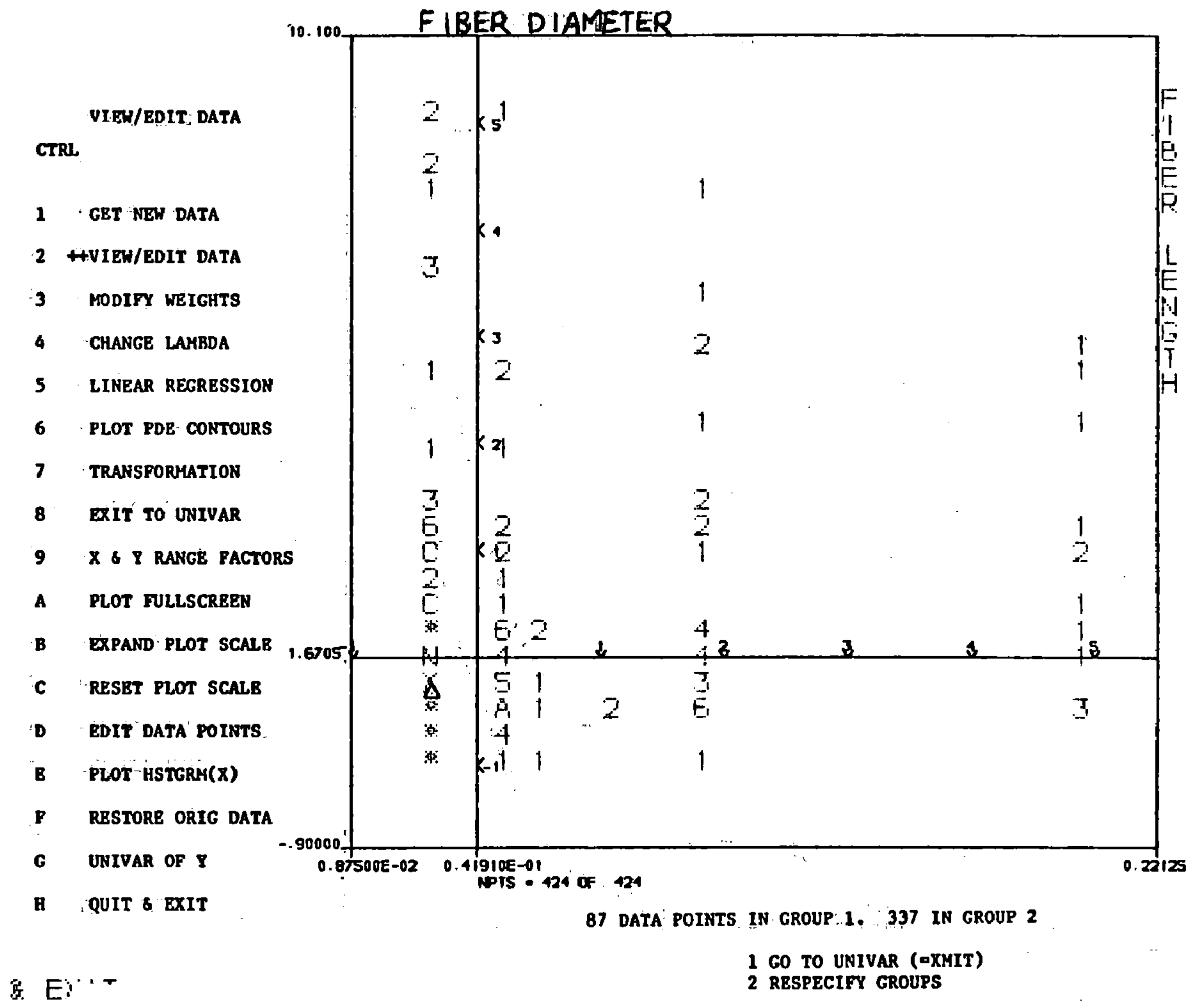
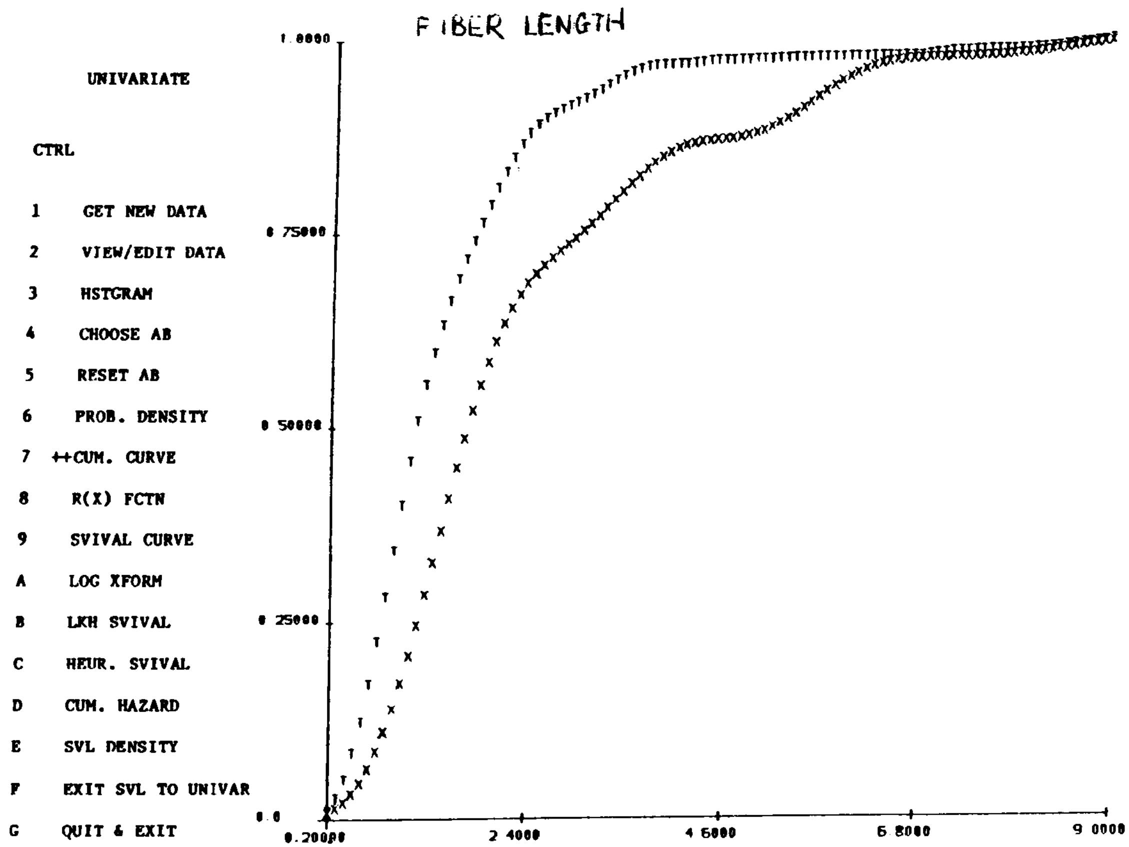


Figure 26. Position of frequency diagram during the separation process.



PARAMETERS	EXCL GRP(X)	INCL GRP(T)
SAMPLE	87	337
EST.MU	1.3440	0.90400
EST.SGMA	0.77291	0.54632
EST.MAX	0.46868	0.67530
MEDIAN	1.6000	1.2000

MAX DIF = 0.26971
SIG. PT (0.05) = .16355

Figure 27. Comparison of cumulative fiber length data for narrow and wide fibers (T - narrow; X - wide).

SECTION 7

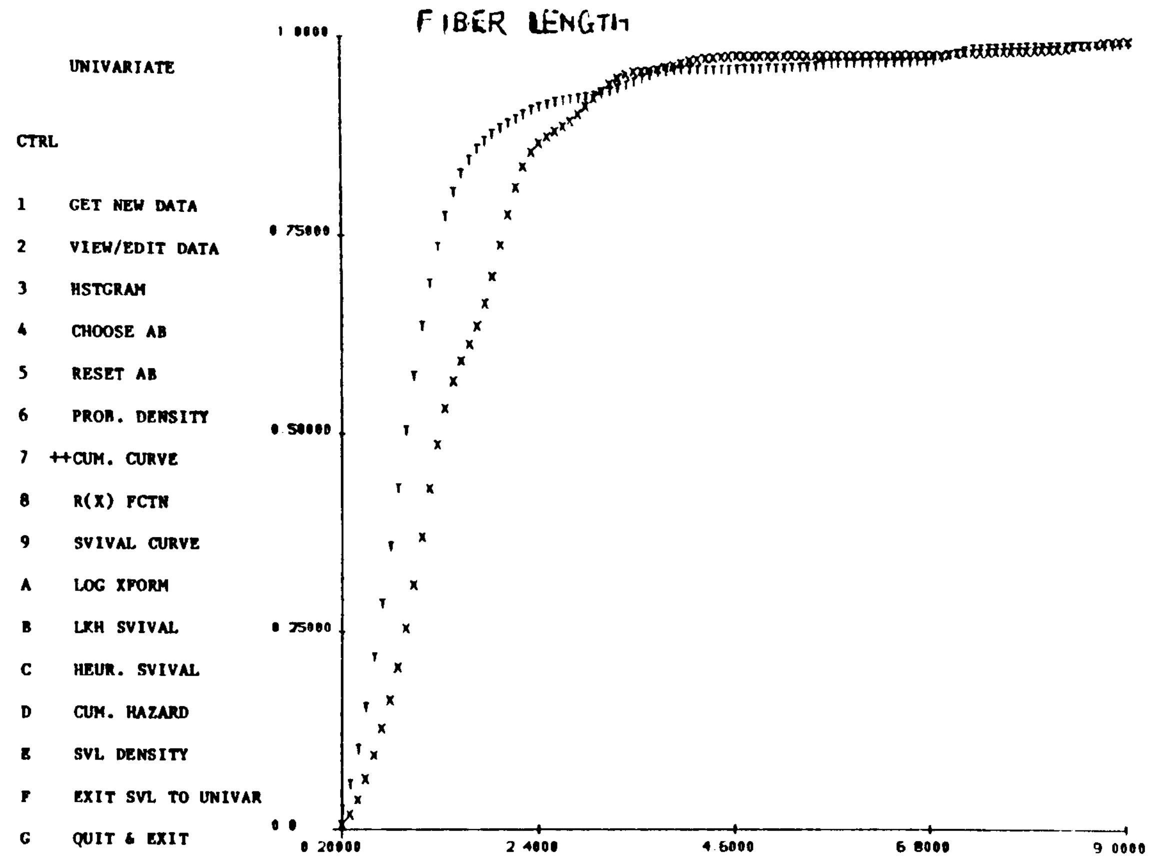
COMPARISON OF BEFORE AND AFTER AC PIPE FOR NARROW FIBER GROUP

Because highly statistically significant results will be described in this section, care was taken to protect against incorrect inference. Hence both transformed and smoothed displays were utilized. The same finding, that fibers tended to be shorter before than after AC pipe, was obtained in all instances.

A nonparametric estimation smoothing technique described in [2] Section 5 was used to obtain Figure 29 using the same data utilized to obtain Figure 28. In both figures there is somewhat less of the ambiguous crossover tendency of the estimated population cumulatives shown in Figure 18. In essence Figures 28 and 18 would have been identical were it not for the removal of thicker fibers as a preliminary to the construction of Figure 28. However, much more striking results were obtained by using a logarithmic transformation as previously described in Section 2.

After using the logarithm of fiber length in place of fiber length plotted on an arithmetic scale the degree of distribution separation and the cause of the ambiguous cumulative crossover tendency was clearly brought into focus in Figure 30 and particularly 31. Before AC pipe narrow fibers tended to be significantly shorter than after AC pipe fibers, which substantiates a result first shown in Figure 5.

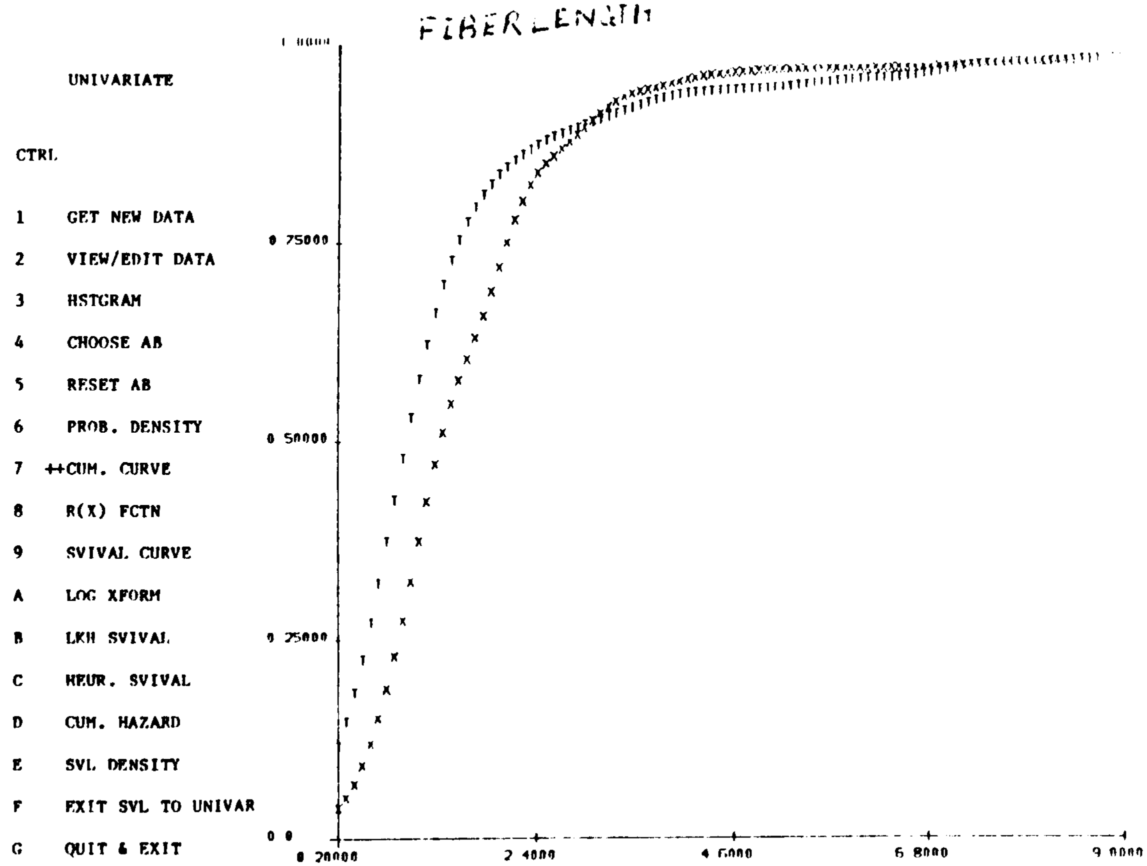
The histograms shown in Figure 32 and 33 demonstrate that although before AC pipe fibers tend in general to be shorter than after AC pipe fibers, a few, in this case about four before AC pipe fibers, are longer than their after AC pipe counterparts. This slight aberration is also illustrated by the upward trend of the right tail of the leftmost curve shown in Figure 31.



PARAMETERS	EXCL GRP(X)	INCL GRP(T)
SAMPLE	233	104
EST.MU	1.0800	0.72800
EST.SGMA	0.54112	0.44742
EST.MAX	0.69943	0.83712
MEDIAN	1.2000	1.000

MAX DIF = 0.26500
SIG. PT (0.05) = .16038

Figure 28. Comparison of cumulative fiber length data before and after A/C pipe for the narrowest fiber group (X axis scaled in microns).



PARAMETERS	EXCL GRP(X)	INCL GRP(T)
SAMPLE	233	104
EST.MU	1.0800	0.81600
EST.SGMA	0.65790	0.65316
EST.MAX	0.57700	0.60065
MEDIAN	1.2000	1.0000

MAX. DIF = 0.20610
SIG. PT (0.05) = .16038

Figure 29. Comparison of cumulative fiber length data before and after A/C pipe for the narrowest fiber group using a smoothing technique (X axis scaled in microns).

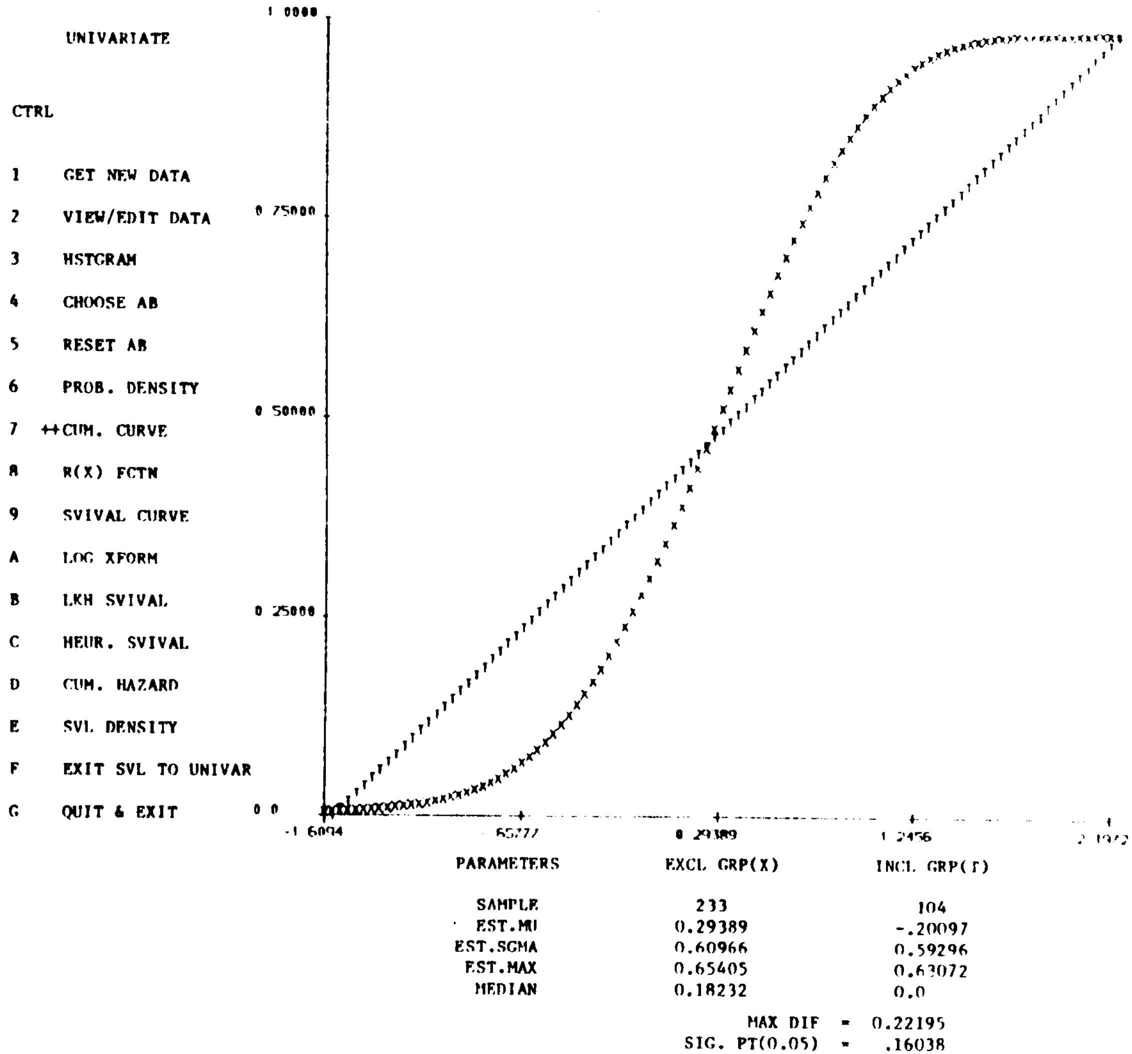


Figure 30. Comparison of cumulative log fiber length data before and after A/C pipe for the narrowest fiber group (X axis in log amicron scale).

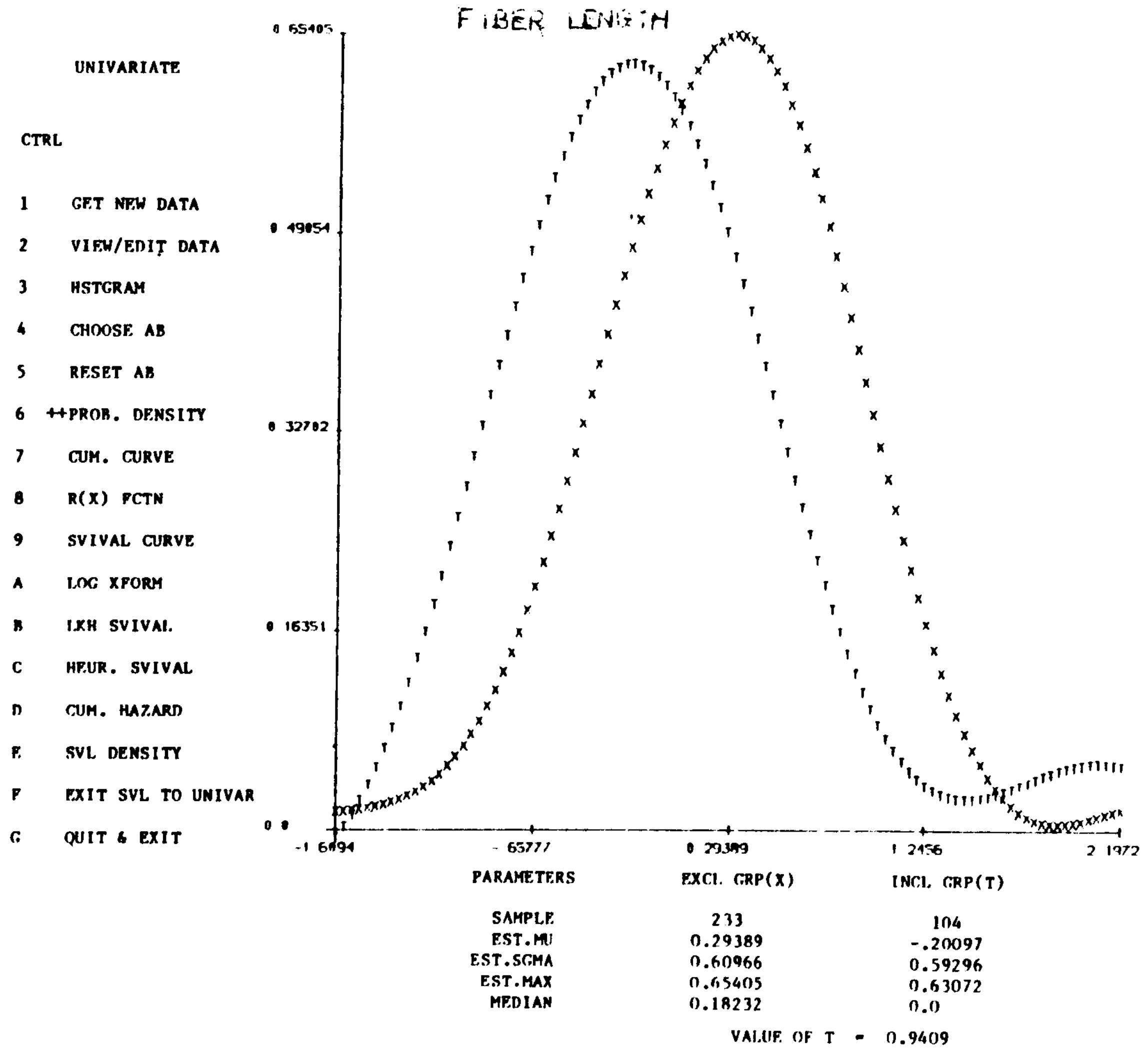


Figure 31. Comparison of estimated fiber size population density curves of fiber length A/C pipe for narrowest fiber group (X axis in micron scale).

UNIVARIATE

CTRL

1 GET NEW DATA

2 VIEW/EDIT DATA

3 ++HSTGRAM

4 CHOOSE AB

5 RESET AB

6 PROB. DENSITY

7 CUM. CURVE

8 R(X) FCTN

9 SVIVAL CURVE

A LOG XFORM

B LKH SVIVAL

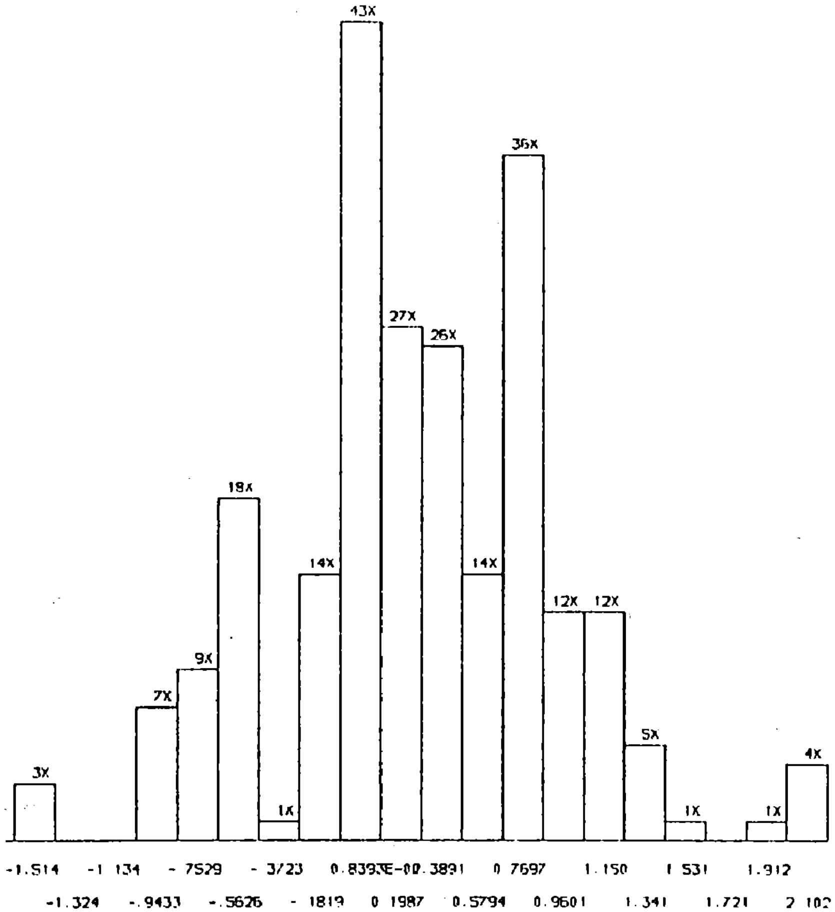
C HEUR. SVIVAL

D CUM. HAZARD

E SVL DENSITY

F EXIT SVL TO UNIVAR

G QUIT & EXIT



NO. OF INTERVAL = 20

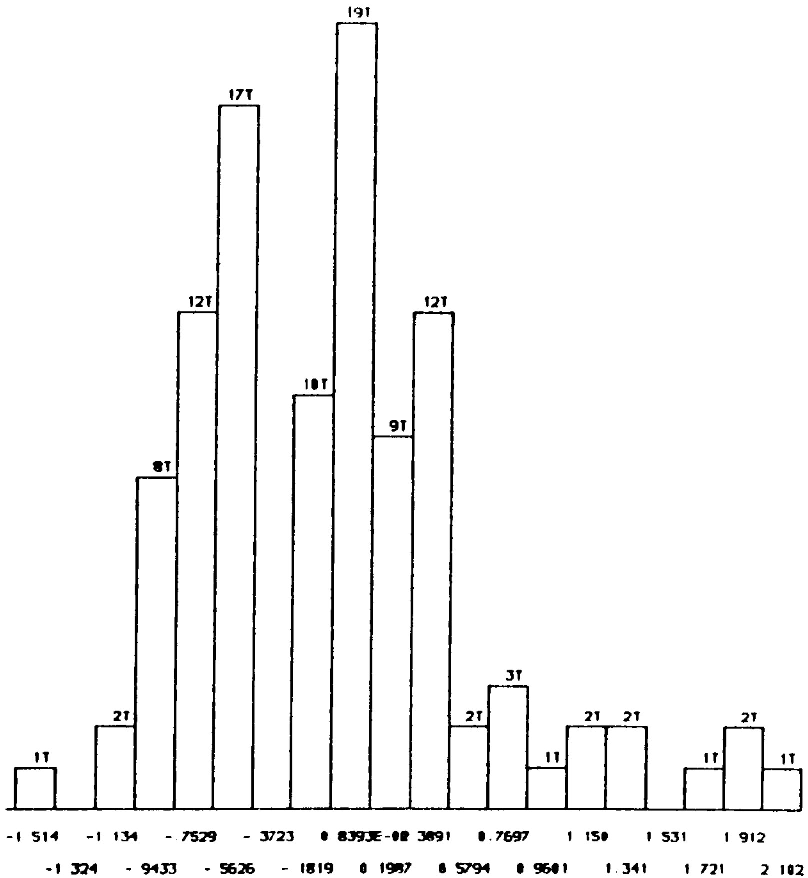
PARAMETERS	EXCL GRP(X)	INCL GRP(T)
SAMPLE	233	104
EST.MU	0.29389	-.20097
EST.SGMA	0.60966	0.59296
EST.MAX	0.65405	0.63072
MEDIAN	0.18232	0.0

Figure 32. Histogram of fiber length data for narrowest fiber group after A/C pipe (X axis in log micron scale).

UNIVARIATE

CTRL

1 GET NEW DATA
2 VIEW/EDIT DATA
3 ++HSTGRAM
4 CHOOSE AB
5 RESET AB
6 PROB. DENSITY
7 CUM. CURVE
8 R(X) FCTN
9 SVIVAL CURVE
A LOG XFORM
B LKH SVIVAL
C HEUR. SVIVAL
D CUM. HAZARD
E SVL DENSITY
F EXIT SVL TO UNIVAR
G QUIT & EXIT



NO. OF INTERVAL = 20

PARAMETERS	EXCL GRP(X)	INCL GRP(T)
SAMPLE	233	104
EST.MU	0.29389	-.20097
EST.SGMA	0.60966	0.59296
EST.MAX	0.65405	0.63072
MEDIAN	0.18232	0.0

Figure 33. Histogram of fiber length data for narrowest fiber group before A/C pipe (X axis in log micron scale).

SECTION 8

COMPARISON OF BEFORE AND AFTER AC PIPE SAMPLES

FOR THE WIDER FIBER GROUP

There were only eighty-seven fibers which were not members of the narrowest fiber group described in the last section. Therefore, the fact that the fiber length distributions for these wider fibers were not significantly dif-different before and after AC pipe does not necessarily imply that there is not a length distribution difference between the two groups of wider fibers.

Figure 34, when compared with either Figure 28 or 29, demonstrates that there is far less observable difference, before and after AC pipe, within the wider fiber group than within the narrowest fiber group. This finding may of course be attributed to the smaller sample sizes available for the wider fiber group. In fact when one uses a log transform, a shift in size, similar to that observed in Figure 29, is apparent. (Of course, since a transformation does not affect the Kolmogorov-Smirnov test, the observed difference is still not statistically significant).

UNIVARIATE

CTRL

1 GET NEW DATA

2 VIEW/EDIT DATA

3 HSTGRAM

4 CHOOSE AB

5 RESET AB

6 PROB. DENSITY

7 ++CUM. CURVE

8 R(X) FCTN

9 SVIVAL CURVE

A LOG XFORM

B LKH SVIVAL

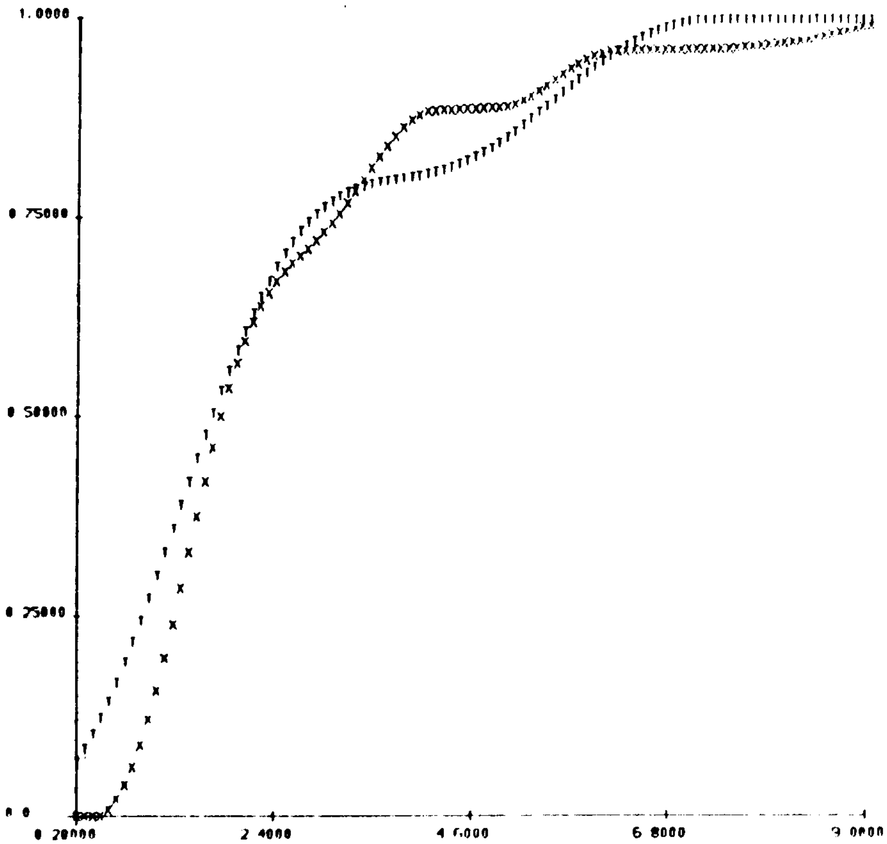
C HEUR. SVIVAL

D CUM. HAZARD

E SVL DENSITY

F EXIT SVL TO UNIVAR

G QUIT & EXIT



PARAMETERS	EXCL GRP(X)	INCL GRP(T)
SAMPLE	54	33
EST.MU	1.4320	1.3440
EST.SGMA	0.70449	1.1423
EST.MAX	0.51531	0.33596
MEDIAN	1.8000	1.5000

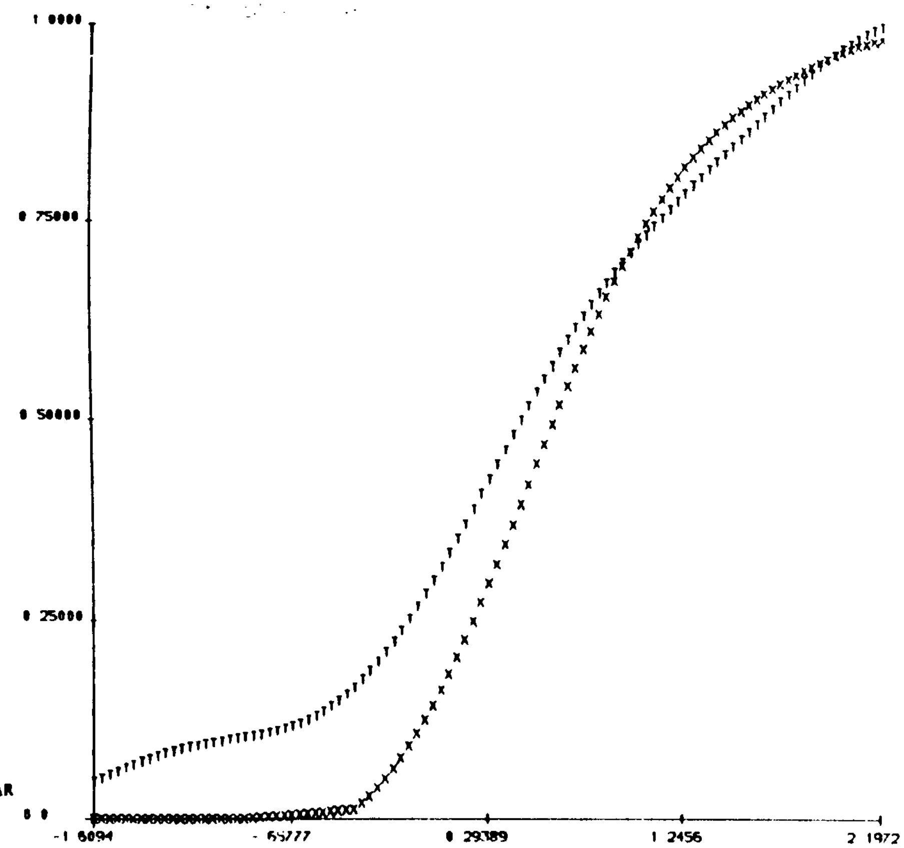
MAX. DIF = 0.15544
SIG. PT (0.05) = .30050

Figure 34. Comparison of cumulative fiber length data before and after A/C pipe for the wider fiber group (X axis in micron scale; T = before; X = after).

UNIVARIATE

CTRL

1 GET NEW DATA
2 VIEW/EDIT DATA
3 HSTGRAM
4 CHOOSE AB
5 RESET AB
6 PROB. DENSITY
7 ++CUM. CURVE
8 R(X) FCTN
9 SVIVAL CURVE
A LOG XFORM
B LKH SVIVAL
C HEUR. SVIVAL
D CUM. HAZARD
E SVL DENSITY
F EXIT SVL TO UNIVAR
G QUIT & EXIT



PARAMETERS	EXCL GRP(X)	INCL GRP(T)
SAMPLE	54	33
EST.MU	0.48423	0.29389
EST.SGMA	0.59065	0.79918
EST.MAX	0.66294	0.49131
MEDIAN	0.58779	0.40547

MAX. DIF = 0.16075
SIG. PT (0.05) = .30050

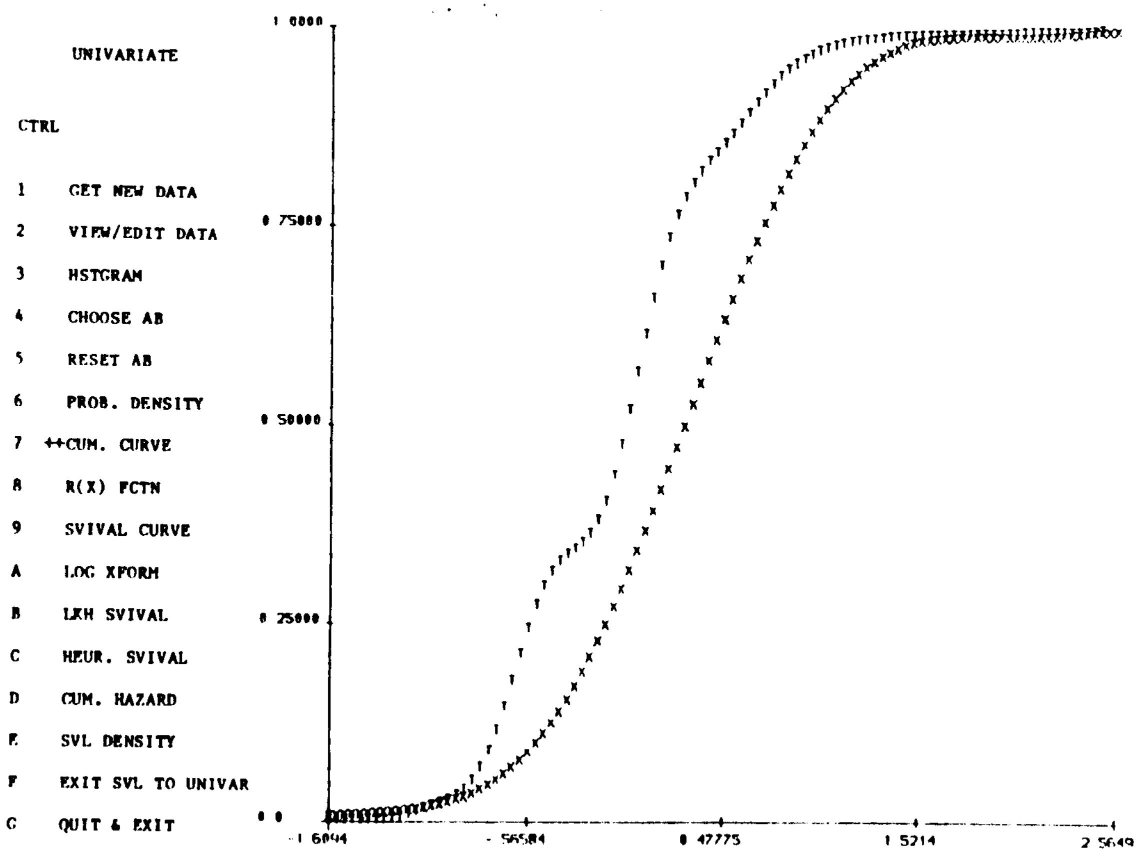
Figure 35. Comparison of cumulative fiber length data before and after A/C pipe for the wider fiber group (X axis in log micron scale; T = before; X = after).

SECTION 9

RAW WATER AND COMBINED AFTER A/C PIPE FIBER LENGTH COMPARISONS FOR THICK FIBERS

To obtain further confirmation that before AC piped fibers had a different length distribution than after AC piped fibers, the data described in Figure 22 was divided into two subgroups. Specifically the n = 233 narrowest out of the n = 287 total after AC pipe fibers and n = 271 narrowest out of the 318 total Crystal Springs raw water samples were selected.

The estimated cumulative shown in Figure 36 repeat, with an even higher level of significance, the general pattern described in Section 5. The density estimates given in Figure 37 demonstrate that particular before AC pipe short length fibers tend to be more common than their after AC pipe counterparts. This finding can be explored in somewhat more detail by means of the histograms given in Figures 38 and 39.



PARAMETERS	EXCL GRP(X)	INCL GRP(T)
SAMPLE	233	271
EST.MU	0.26903	0.18572E-01
EST.SGMA	0.61530	0.34404
EST.MAX	0.64837	1.1438
MEDIAN	0.18232	0.0

MAX DIF = 0.29213
SIG. PT (0.05) = .12150

Figure 36. Comparisons of pooled fiber length data after A/C pipe and raw water fiber length data for the narrow fiber ranges (X axis in log micron scale).

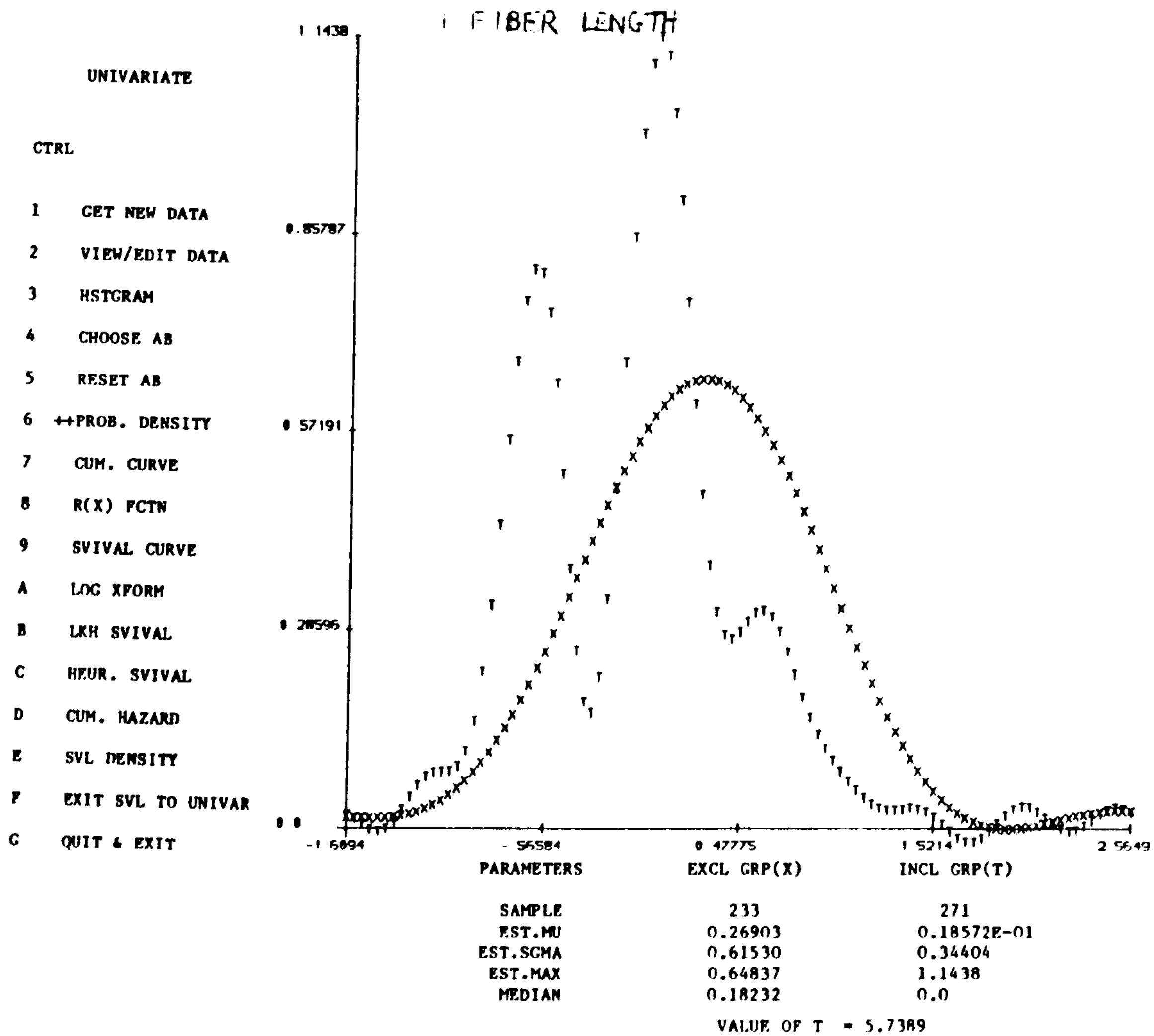
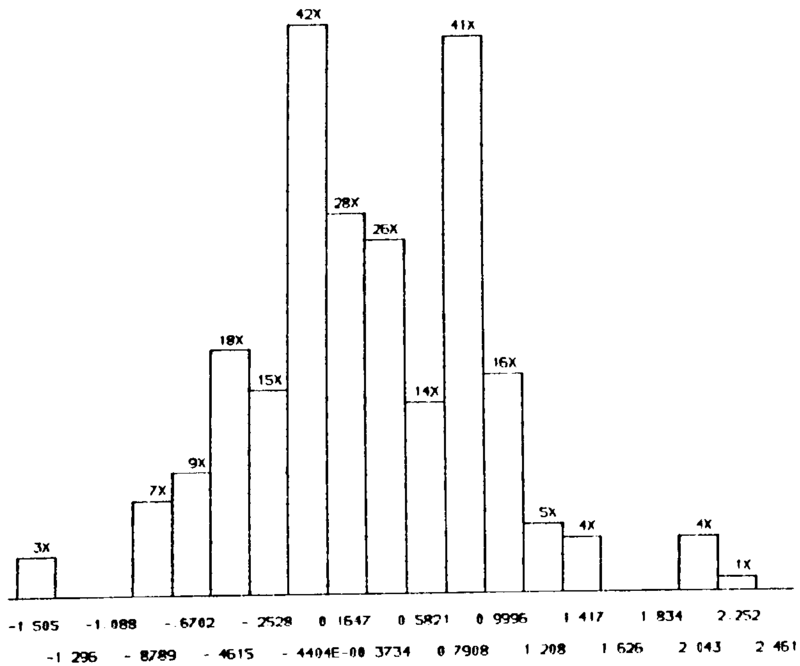


Figure 37. Comparison of estimated population density curves for pooled fiber length data after A/C pipe and raw water fiber length data for the narrow fiber ranges (X axis in log micron scale).

UNIVARIATE

CTRL

1 GET NEW DATA
2 VIEW/EDIT DATA
3 ++HSTGRAM
4 CHOOSE AB
5 RESET AB
6 PROB. DENSITY
7 CUM. CURVE
8 R(X) FCTN
9 SVIVAL CURVE
A LOG XFORM
B LKH SVIVAL
C HEUR. SVIVAL
D CUM. HAZARD
E SVL DENSITY
F EXIT SVL TO UNIVAR
G QUIT & EXIT



PARAMETERS	EXCL GRP(X)	INCL GRP(T)
SAMPLE	233	271
EST.MU	0.26903	0.18572E-01
EST.SGMA	0.61530	0.34404
EST.MAX	0.64837	1.1438
MEDIAN	0.18232	0.0

Figure 38. Histogram of narrow fiber length data after A/c pipe (X axis in log micron scale).

UNIVARIATE

CTRL

1 GET NEW DATA

2 VIEW/EDIT DATA

3 ++HSTGRAM

4 CHOOSE AB

5 RESET AB

6 PROB. DENSITY

7 CUM. CURVE

8 R(X) FCTN

9 SVIVAL CURVE

A LOG XFORM

B LKH SVIVAL

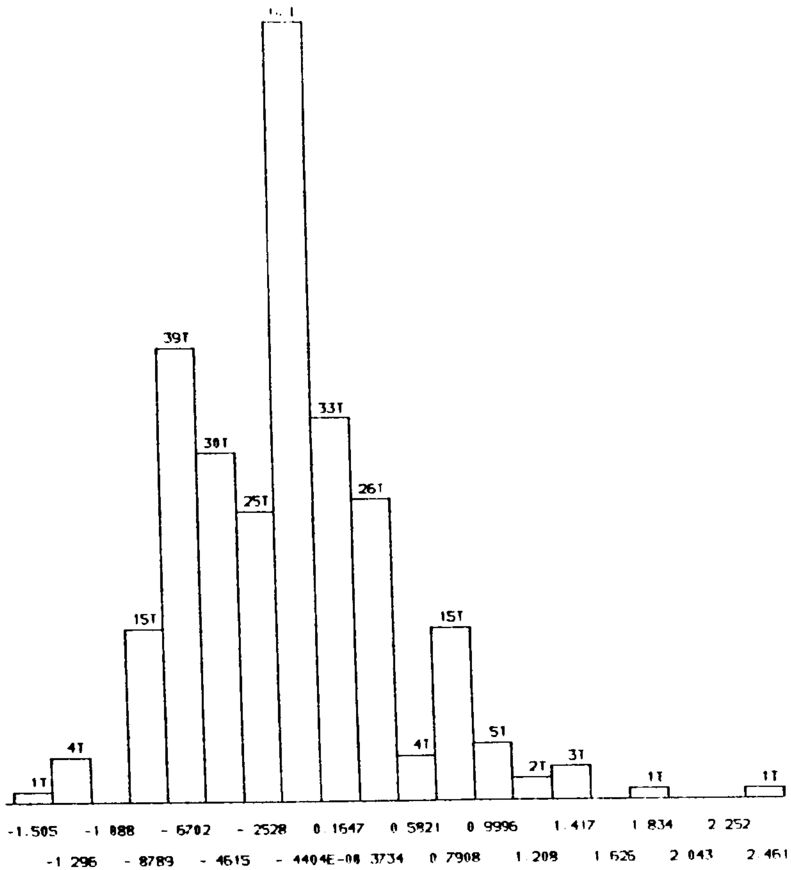
C HEUR. SVIVAL

D CUM. HAZARD

E SVL DENSITY

F EXIT SVL TO UNIVAR

G QUIT & EXIT



NO. OF INTERVAL = 20

PARAMETERS	EXCL GRP(X)	INCL GRP(T)
SAMPLE	233	271
EST.MU	0.26903	0.18572E-01
EST.SGMA	0.61530	0.34404
EST.MAX	0.64837	1.1438
MEDIAN	0.18232	0.0

Figure 39. Histogram of narrow fiber length data for raw water (X axis in log mircon scale).

SECTION 10

RAW WATER AND COMBINED AFTER A/C PIPE FIBER LENGTH COMPARISONS FOR THICK FIBERS

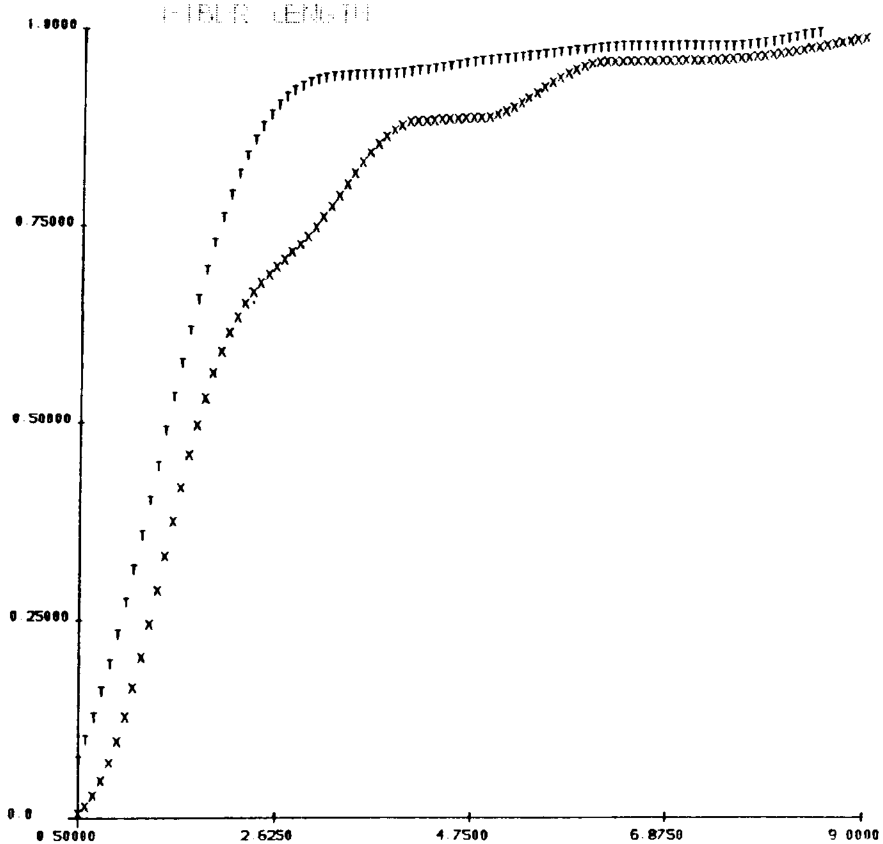
As shown by the fiber length cumulative given in Figure 40, there was a non-statistically significant tendency for naturally occurring water to have shorter fibers than after AC piped water, when only wide fibers were considered.

Note that the sample sizes n = 54 and n = 47 given after the word SAMPLE at the bottom of Figure 40, plus the n = 233 and n = 271 sample sizes of Figure 36 add respectively to n = 287 and n = 318, the sample sizes listed in Figure 22.

UNIVARIATE

CTRL

1 GET NEW DATA
2 VIEW/EDIT DATA
3 HSTGRAM
4 CHOOSE AB
5 RESET AB
6 PROB. DENSITY
7 ++CUM. CURVE
8 R(X) FCTN
9 SVIVAL CURVE
A LOG XFORM
B LKH SVIVAL
C HEUR. SVIVAL
D CUM. HAZARD
E SVL DENSITY
F EXIT SVL TO UNIVAR
G QUIT & EXIT



PARAMETERS	EXCL GRP(X)	INCL GRP(T)
SAMPLE	54	47
EST.MU	1.4350	1.3500
EST.SGMA	0.70349	0.75733
EST.MAX	0.51816	0.52220
MEDIAN	1.8000	1.4000

MAX DIF = 0.20690
SIG. PT (0.05) = .27130

Figure 40. Comparison of wide fiber length data after A/C pipe and wide fiber length data data from raw water (X axis in micron scale).

SECTION 11

DISCUSSION

The overall conclusions suggested by our study are as follows:

a) There seems to be very little difference between fiber length distributions before and after water treatment at one site.

b) Before AC pipe samples tend to have shorter fibers than after AC piped samples.

c) The above difference is more noticeable when the narrow fiber subgroups are considered apart from their wider fiber counterparts.

There are several possible hypotheses concerning these conclusions. The most reasonable hypothesis is that fibers coming from the AC pipe interior are of the commercial variety of asbestos and these fibers tend to be longer than the fibers found in the natural water around San Francisco. An alternate, less plausible argument could be made. Consider that larger bundles of fibers may tend to fragment or chip as they pass through AC pipe. In the electron microscope fiber measurement process one chunky "fiber" was observed which might have been composed of a large number of narrower fibers. Such a fiber could easily leave a trail of fragments along its path through a long section of pipe.

As shown in Figures 41 and 42 there is a slight, but highly statistically significant positive association between fiber length and width. (Note the t value of 7.009 at the bottom of Figure 42). Now since a wider particle would also tend to contain long fibers, the fragments left during its passage through a long section of pipe would tend to be longer than the average length of fiber entering the pipe.

VIEW/EDIT DATA

CTRL

1 GET NEW DATA

2 ++VIEW/EDIT DATA

3 MODIFY WEIGHTS

4 CHANGE LAMBDA

5 LINEAR REGRESSION

6 PLOT PDE CONTOURS

7 TRANSFORMATION

8 EXIT TO UNIVAR

9 X & Y RANGE FACTORS

A PLOT FULLSCREEN

B EXPAND PLOT SCALE

C RESET PLOT SCALE

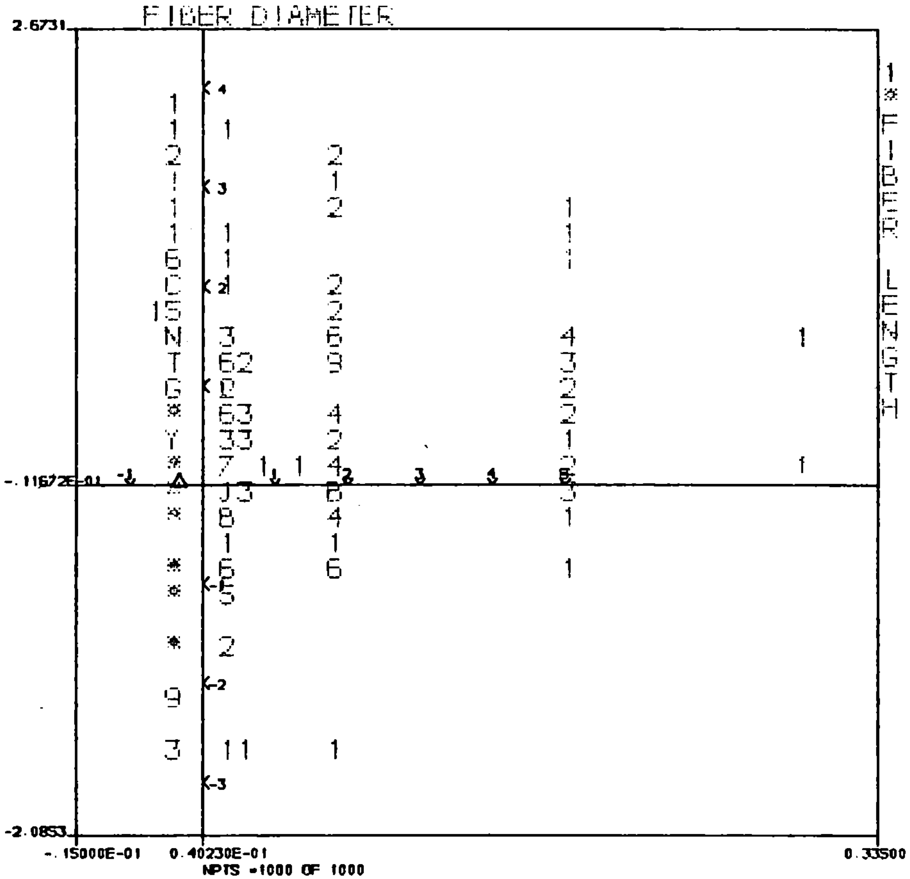
D EDIT DATA POINTS

E PLOT HSTGRM(X)

F RESTORE ORIG DATA

G UNIVAR OF Y

H QUIT & EXIT



COR(X,Y) = 0.233
S.D. (X) = 0.317E-01
S.D. (Y) = 0.585

Figure 41. Frequency diagram of diameter and length for combined samples before A/C pipe (maximum sample size that can be analyzed using GRAFSTAT).

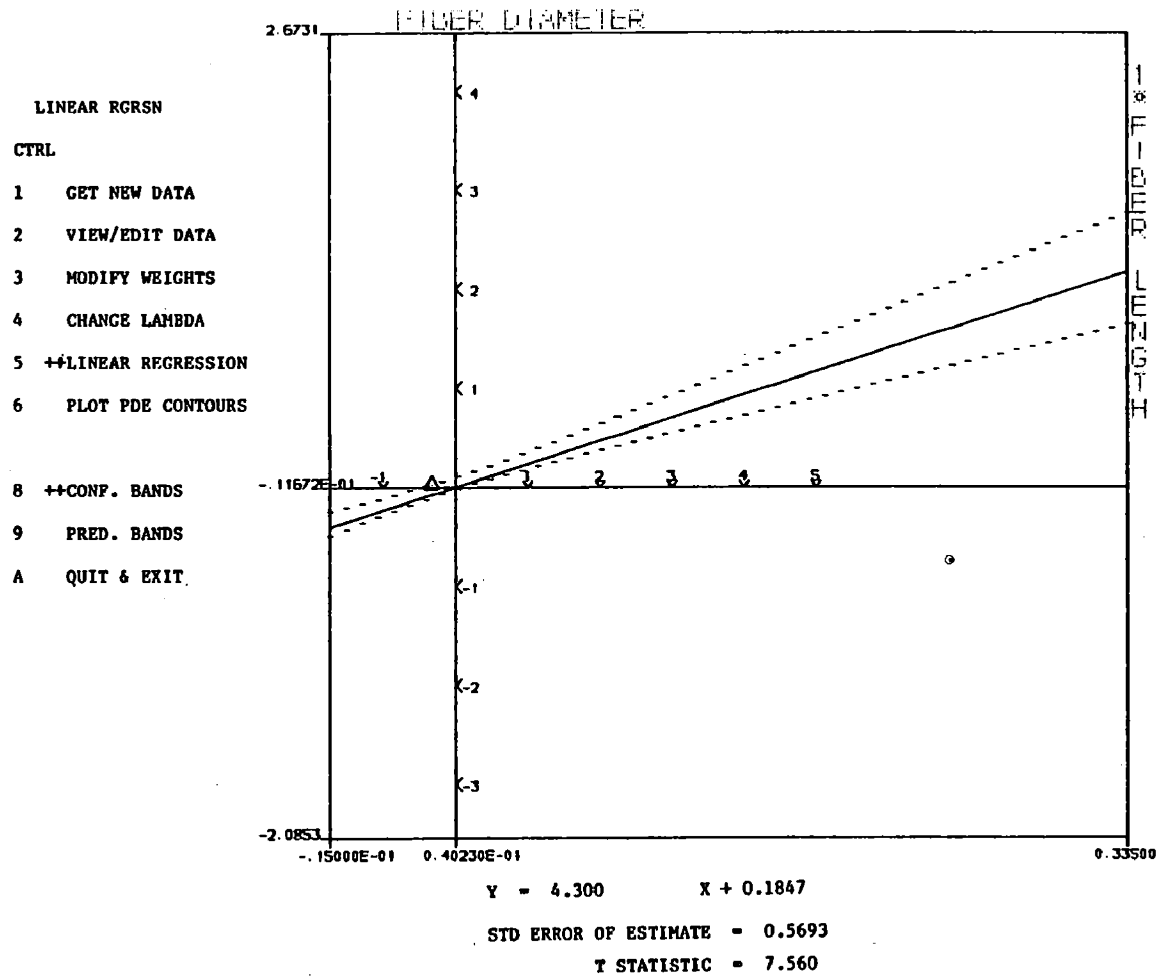


Figure 42. Plot of linear regression for data shown in Figure 40 (α = .05 confidence band).

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16. ABSTRACT

A statistical study of asbestos fiber size characteristics was conducted using data obtained from a variety of San Francisco Bay Area water systems. Particular emphasis was placed on comparison of fiber length distributions for samples collected from pre and post asbestos cement (AC) pipe systems. Significant differences were detected between the fiber size distributions in samples of raw water and water collected after a length of AC pipe. Little difference was detected between the fiber size distributions of a raw water sample and a treated water sample. It was also shown that before and after AC pipe, fibers in the water differed most significantly in the length distributions of narrow fibers.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Asbestos, Serpentine, Potable water	Health Effects	06 F

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